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BALLISTIC ANALYSIS LABORATORY

TECHNICAL REPORT No. 64

MAY 1967

EFFECT OF PROTECTIVE PASSIVE DEFENSE MEASURES ON VULNERABILITY OF UNARMORED AUTOMOTIVE GROUND VEHICLES: VULNERABILITY OF A 2.5-TON CARGO TRUCK TO SINGLE-SHOT FRAGMENT IMPACTS AND TO DIRECT HITS WITH SMALL SHAPED CHARGES (U)

JOHN P. WILSON

Research Sponsored by
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland
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(UNCLASSIFIED) ABSTRACT

The vulnerability of the U. S. Army, model M-34, 2.5-ton, 6 x 6, gasoline powered cargo truck to single-shot fragment impacts and to direct hits with single, small, shaped charges is discussed. The basic version of the vehicle is unarmored. The degradation of vulnerability resulting from protective passive defense measures is investigated by considering the basic version and three modified versions of the vehicle. The four versions of the vehicle differ only in hood top and hood side panel thickness or in other protection afforded to engine components.

Nine fragment impact weights, ranging from 5 grains to 1000 grains, and sixteen fragment impact velocities, ranging from 125 fps to 10,000 fps are considered relative to each of two mobility kill categories, A (two-minute) and B (twenty-minute), and to each version of the vehicle. Two shaped charges are considered relative to each of the two mobility kill categories, A and B, and to the basic version of the vehicle.

Estimates of vehicle vulnerable area, averaged over azimuth for selected elevation angles and averaged over both elevation and azimuth, are presented for each of the four versions of the vehicle relative to various combinations of fragment impact weight, fragment impact velocity, and kill category. Similar averaged vulnerable area estimates are presented for the basic vehicle only relative to each of the two shaped charges.

(UNCLASSIFIED) ACKNOWLEDGEMENT

The author acknowledges the significant contribution of Mr. Miles W. Sandin, of this laboratory, in the production of the target vulnerability data presented in this report. Mr. Sandin developed the computer programs employed in the processing of basic input data and the generating of target vulnerable areas. He also assisted in the planning and supervising of the shaped charge experimental firing program described in Section III.

The author also expresses appreciation to Mr. Adam Korba of the U. S. Army Ballistic Research Laboratories for his efforts in the directing and expediting of the shaped charge experimental firing program and for technical advice rendered in the planning of the program.

ILLUSTRATIONS AND TABLES (cont.)

(CONFIDENTIAL) SUMMARY

The main purpose of this report is to present a discussion of the degradation in the vulnerability of a representative, unarmored, gasoline powered, cargo truck to single-shot fragment impacts which results from the employment of certain protective passive defense measures. In accomplishing this purpose, the report presents vulnerability data for the basic version and for several modified versions of the vehicle relative to single-shot fragment impacts with a wide range of fragment weights and velocities. The report also presents a discussion of the vulnerability of the basic version to attack with single, small, shaped charges of two different sizes.

The vehicle considered is the model M-34, 2.5-ton, U. S. Army cargo truck. The basic and modified versions of the vehicle are described in Section I; additional details are presented in References 1, 2, and 3. The protective passive defense modifications considered are delineated in Section I. Briefly, they amount to the increasing of hood top thickness and of hood side panel thickness and to the adding of a metal top cab closure and metal louvres in front of the radiator.

The target vulnerability information presented herein is based on: 1) a detailed study of the model M-34 vehicle and its components, 2) data obtained in previous investigations, such as those outlined in References 4 and 5 and in several of the reports listed in the Bibliography, of the vulnerability of gasoline powered vehicles to single-shot impacts, and 3) a limited experimental firing program, described in Section III, involving two small shaped charges and the basic version of the vehicle.

Estimates of vehicle vulnerable area are presented for

both A (two-minute) and B (twenty-minute) mobility kill categories for selected fragment impact weight-velocity combinations relative to each of four versions of the target vehicle and for each of two small shaped charges relative to the basic version of the vehicle. Fragment impact weights considered range from 5 to 1000 grains; fragment impact velocities considered range from 125 to 10,000 feet per second. Consideration is given to extremely small impact velocities in an attempt to define accurately for each fragment impact weight considered the vulnerability cut-off velocity (i.e., for a given fragment impact weight, the smallest value of fragment impact velocity which has associated with it a non-zero estimate of vehicle vulnerable area). The two small shaped charges have, respectively, diameters of 1.0 and 1.8 inches. Further details on the shaped charges are provided in Section III.

Values of vehicle vulnerable area $\bar{A}_v^*$, averaged over both azimuth and elevation, versus fragment impact velocity for several given fragment impact weights are presented graphically for the basic version of the vehicle. Comparable values of $\bar{A}_v^*$ for each of the four versions of the vehicle considered are presented in tabular form for 90 of the fragment impact weight-velocity combinations considered. Values of vehicle vulnerable area $\bar{A}_v$, averaged over azimuth only for selected elevation angles, are presented in tabular form for 90 of the fragment impact weight-velocity combinations considered. Values of vehicle vulnerable area $\bar{A}_v^*$ and $\bar{A}_v$ associated with the two shaped charges are presented in tabular form.

The results of the investigation of the vulnerability of the model M-34 vehicle (basic version) to single-shot fragment impacts are summarized below in Table I. For each of the mobility kill categories (A and B) and for each fragment impact weight w, values of vehicle vulnerable area $\bar{A}_v^*$,

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TABLE I

VULNERABLE AREA $\bar{A}_v^*$ (ft^2) OF BASIC VERSION OF TARGET VEHICLE : (U)

Mobility Kill Category	w (grains)	v (fps) 1000	4000 - 7000	10,000
A	5	0.00	0.00	0.00
	10	0.00	0.12	0.00
	15	0.01	0.18	0.00
	30	0.01	0.22	0.01
	60	0.03	0.27	0.20
	120	0.08	0.30	0.24
	240	0.14	0.36	0.28
	500	0.24	0.37	0.36
	1000	0.31	0.37	0.37
B	5	0.53	0.53	0.53
	10	0.54	1.64	0.54
	15	0.57	1.94	0.54
	30	0.68	2.59	0.57
	60	0.89	3.04	2.16
	120	1.43	3.25	2.86
	240	1.89	3.49	2.98
	500	2.56	3.63	3.22
	1000	2.95	3.66	3.29

averaged over both azimuth and elevation, are presented for the lowest (1000 fps) and highest (10,000 fps) values of fragment impact velocity v considered for tabular data. In each case, a relative maximum value of $\bar{A}_v^*$, which occurs in the fragment impact velocity range of 4000 to 7000 fps for each fragment weight, is also presented.

For single-shot fragment impact weight w, in grains, in the range $5 \leq w \leq 1000$, $\bar{A}_v^*$ appears, in general, to be a monotone, non-decreasing function of impact velocity v, in fps, in the interval $1000 \leq v \leq 5000$. A relative maximum value of $\bar{A}_v^*$ occurs for each fragment weight in the mid-range of velocities $4000 \leq v \leq 7000$ considered. For impact velocities $v \geq 7000$, $\bar{A}_v^*$ tends to become a gradually to (in some cases) sharply decreasing function of v. The phenomenon of a relative maximum value of $\bar{A}_v^*$ for a given fragment weight in the velocity interval indicated is not unexpected and has been discussed in previous reports, e.g., in References 4 and 5.

The degradation in vehicle vulnerability to single-fragment impact which results from increasing hood top and hood side panel thickness and from adding radiator louvres and metal cab top to basic version equipment is indicated below in Table II. For a given mobility kill category, fragment impact weight, and associated maximum value of vehicle vulnerable area $\bar{A}_v^*$ for the basic version T_1 of the vehicle, Table II presents for each modified vehicle version; T_2, T_3, and T_4 (listed in order of increasing protective passive defense features); the percent of decrease in the maximum value of $\bar{A}_v^*$ for the modified version relative to the maximum value of $\bar{A}_v^*$ for the basic version.

Table II reveals that the decrease in vulnerable area of the basic version of the vehicle attributable to the protective features of the

(CONFIDENTIAL) TABLE II

DEGRADATION OF MAXIMUM VEHICLE VULNERABLE AREA $\bar{A}_v^*$ (ft^2) OF BASIC VERSION OF VEHICLE RESULTING FROM EMPLOYMENT OF PROTECTIVE PASSIVE DEFENSE MEASURES: (U)

Mobility Kill Category	w (grains)	max $\bar{A}_v^*$ (T_1)	Percent of Decrease in $\bar{A}_v^*$ T_2	T_3	T_4
A	5	0.00	0	0	0
	10	0.12	25	42	58
	15	0.18	11	28	39
	30	0.22	5	9	18
	60	0.27	0	4	15
	120	0.30	0	0	10
	240	0.36	0	0	8
	500	0.37	0	0	3
	1000	0.37	0	0	0
B	5	0.53	0	0	100
	10	1.64	10	16	26
	15	1.94	6	11	13
	30	2.59	5	10	13
	60	3.04	1	2	5
	120	3.25	0	1	3
	240	3.49	0	0	1
	500	3.63	0	0	0
	1000	3.66	0	0	0

T_1 = basic version of vehicle
T_2, T_3, T_4 = modified versions of vehicle

See Section I for details of various vehicle versions.

modified versions is most noticeable for certain ranges of fragment impact weight w. Increasing hood top and side panel thickness from 0.040 in. (version T_1) to 0.060 in. (version T_2) has greatest effect for fragment impact weights of 10 to 15 grains; increasing such plating thickness to 0.080 in. (version T_3) has greatest effect for fragment impact weights of 10 to 30 grains; increasing existing plating thickness to 0.080 in. and adding 0.080 in. radiator louvres and a metal cab top (version T_4) has greatest effect for fragment impact weights of 5 to 30 grains. The addition of radiator louvres and a metal cab top, which is the difference between versions T_3 and T_4, accounts for considerably greater decrease in vulnerable area than is accounted for by the difference in hood top and hood side panel thickness between versions T_1 and T_3. This is especially noticeable in the case of mobility kill B Category since the louvres and cab top afford considerable protection to one of the larger components vulnerable in the B Category, i.e., to the radiator.

The results of the investigation of the vulnerability of the model M-34 vehicle (basic version) to attack with the two shaped charges considered are summarized below in Table III.

(CONFIDENTIAL) TABLE III

VULNERABLE AREA $\bar{A}_v^*$ OF BASIC VERSION OF VEHICLE ASSOCIATED WITH SHAPED CHARGES: (U)

Mobility Kill Category	Charge Diameter d (in.)	$\bar{A}_v^*$ (ft^2)
A	1.0	1.75
	1.8	2.05
B	1.0	4.68
	1.8	5.60

For each of the two shaped charges, identified by charge diameter d, and for each of two mobility kill categories, A and B, values of vehicle vulnerable area $\bar{A}_v^*$, averaged over azimuth and elevation, are presented.

Differences between comparable values, i.e., values associated with a given kill category, of vehicle vulnerable area for the two shaped charges are not large. On the average, the vehicle vulnerable area associated with the larger (1.8 in. diameter) charge is less than twenty-percent greater than that associated with the smaller (1.0 in. diameter) charge.

There is a marked difference between comparable values of vehicle vulnerable area associated with single-fragment impact (Table I) and those associated with the shaped charges (Table III). The greatest differences are in values associated with mobility kill in the A Category. These differences reflect, largely, the fact that the fuel tank is assumed vulnerable in the A Category to shaped charges but not to fragments. The differences in values of vehicle vulnerable area associated with mobility kill in the B Category are not so great since the fuel tank is vulnerable in the B Category, although not to the same extent, to both shaped charges and fragments.

(CONFIDENTIAL) INTRODUCTION

There are numerous different types of military vehicles which fall into the general classification of unarmored, gasoline powered, automotive ground vehicles. The extensive use of such vehicles in almost all phases of full scale and limited warfare and in maneuvers attests to the logistical significance of the vehicles. Knowledge of the vulnerability of this class of vehicles to various types of weapons is of importance to both antagonists in any military engagement or operation in which the vehicles are involved, to war games analysts, to weapon designers, and to automotive vehicle designers.

In cooperation with the Ballistic Research Laboratories at Aberdeen Proving Ground, Maryland, this laboratory (Ballistic Analysis Laboratory of the Institute for Cooperative Research of The Johns Hopkins University) has undertaken and is presently engaged in a number of studies dealing with the vulnerability of automotive ground vehicles in general and with the vulnerability of specific "targets" belonging to this class of vehicles. These vulnerability studies are discussed in a series of technical reports (of which the present report is one) which have been published by this laboratory. These reports present the results of the studies, a description of experimental procedures and techniques involved, and, where appropriate, conclusions which may be drawn from the data generated, comments on applications of the data, and suggestions for future studies. A bibliography listing the BAL reports referred to above is appended at the end of this report.

This report presents the results of two recent vehicle vulnerability studies in which the same vehicle (the U. S. Army, 2.5-ton, 6 x 6, gasoline powered, model M-34, cargo truck) is considered as a target vehicle. The first, and more extensive, of the two studies is concerned with the effect on the vulnerability of the target vehicle of applying certain passive defense measures. The second study is concerned with the vulnerability of the target vehicle to direct hits with single, small shaped charges.

For a number of years, varying degrees of interest have been expressed in passive defense measures applicable to unarmored, automotive ground vehicles. Recently, the interest has centered around the protective aspect of passive defense. Short of armoring the vehicles, there are some protective measures applicable to unarmored vehicles which, as previously noted in Reference 4 (p. 35 ff.), appear worthy of consideration. The measures described herein include: 1) increasing hood top and side panel thickness, 2) adding a hard top (metal) cab closure, 3) providing radiator louvres. Comparable vulnerability data are presented for each of four versions of the vehicle relative to a considerable range of fragment impact weights and velocities. The data are the results of a theoretical, parametric study in which the parameters are fragment impact weight, fragment impact velocity, and vehicle outer surface features.

Requests for estimates of the vulnerability of several ground vehicles to small shaped charge projectiles led to a limited experimental study of the effects of shaped charges on the target vehicle. A small number of shaped charges were fired against the target. Descriptions of target damage caused by each shaped charge fired are presented together with vehicle vulnerability estimates based on the damage observed in the firing program.

The vehicle vulnerability information in this report is presented in terms of vulnerable area. The concept of vulnerable area and its applicability to vehicle vulnerability studies is discussed in some detail in previous reports published by BAL, particularly in an appendix to Reference 5. For the purposes of this report, the vulnerability of the model M-34 vehicle is considered to be a function of a number of components which the vulnerable portions of the vehicle comprise.

The methods used in determining values of vulnerable area for the target vehicle, relative to the various combinations of fragment impact weight and velocity and to the two shaped charges considered, are essentially those presented in Section VI of Reference 5. Component data required for the present study were obtained from several sources. The type, location, and masking of various vulnerable components were obtained from an examination of an M-34 vehicle at Aberdeen Proving Ground. Component vulnerability data relative to fragment impacts were obtained from previous vulnerability investigations of similar vehicles (See Bibliography.). Component vulnerability data relative to small shaped charges were obtained from a limited firing program described in Section III. A study of the resistance of various metallic materials to perforation by fragments (Reference 7) provided considerable supplementary data.

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SECTION I

(UNCLASSIFIED) TARGET DESCRIPTION

Similarities between Target Vehicle and Other Models

Listed below are twenty four models of 2.5-ton, 6 x 6, U. S. Army trucks, which are described in References 1, 2, or 3.

M-34, M-35, and M-36	cargo,
M-44, M-45, M-46, M-57 and M-58	chassis,
M-47, M-59, and M-342	dump,
M-48 and M-275	tractor,
M-49	gasoline tank,
M-50	water tank,
M-60	light wrecker,
M-108	crane,
M-109 and M-512	shop van,
M-292	expansible van,
XM-472	missile firing data computer van,
XM-567	electronic van,
V-17A/MTQ	telephone construction and maintenance, and
V-18A/MTQ	earth boring machine and pole setter

All of these trucks have identical engines, power trains, axles, and brake systems. The various models differ only in wheelbase, wheels, and the inclusion or omission of details as required by their particular service.

The model M-34 vehicle is the target vehicle considered in this report. Since the vulnerability data generated for the target vehicle are mainly based on the vulnerability of engine components, most of these data will be directly applicable to the other twenty-three models listed above, to variants of these models, and to several other models employing the same engine.

General Description of Target Vehicle

The model M-34 vehicle is a 2.5-ton, 6 x 6, U. S. Army cargo truck, classified Standard B(OTCM 37119). It is a heavy duty carrier of personnel and cargo. It is a six wheel drive, single tired vehicle with a 12-foot steel body. Cargo racks and tarpaulin racks are provided and are removable. The lower portion of the side racks can be swung down for seats when the vehicle is employed as a troop carrier. A spare wheel is carried below the chassis frame at the left front corner of the body. The fuel tank, which has a 50-gallon capacity, is located on the extreme right side of the vehicle, below the cargo bed, and immediately behind the cab area. The model M-34 vehicle comes equipped either with or without a front winch.

The target vehicle employs the model M-44 chassis. This chassis is equipped with one driving front axle and two driving rear axles. Provision is made for normal driving to be done by the rear axles only. If the rear wheels lose traction, the front axle is automatically engaged through the transfer and remains engaged until the rear wheels regain traction.

Power is supplied by a gasoline type, 6 cylinder, 4 cycle, water cooled engine with overhead valves and removable wet sleeve cylinders. The air compressor, carburetor, clutch, distributor, fuel pump, generator, oil filter, and starter are mounted on the engine. The transmission, mounted on the rear of the engine has five speeds forward and one reverse. The transfer is mounted behind the transmission. The clutch is a single, dry plate type attached to the flywheel.

The cab is a metal open top structure, approximately 33 inches high, which surrounds the driver's compartment. A two piece windshield is

mounted at the rear of the cowl. An instrument panel, below the windshield, serves as a support for the steering jacket assembly and as a mounting for instruments and accessories. The cab is furnished with an adjustable driver's seat and a companion seat. A door is provided at each side. The cab may be covered by a canvas tarpaulin or by a metal, hard top closure.

TABLE IV

PHYSICAL CHARACTERISTICS AND PERFORMANCE DATA
FOR
MODEL M-34 VEHICLE

Length, overall:	
w/winch	275 in.
w/o winch	262 in.
Wheelbase	154 in.
Height, overall, empty	109 in.
Width, overall	88 in.
Weight, net:	
w/winch	12,190 lb.
w/o winch	11,775 lb.
Engine:	
manufacturer	Reo Motors Inc.
model	OA-331
type	valve in head, 4 cycle
cylinders	6, in line
governed speed	3,400 rpm.
brake horsepower	146 at 3,400 rpm.
Turning radius	36 ft.
Ground clearance	14 in.
Fording depth:	
w/fording kit	72 in.
Fuel consumption	6 mpg.
Cruising range	350 mi.
Allowable speed (governed)	58 mph.

Table IV, above, presents some pertinent physical characteristics and performance data for the target vehicle. Additional tabulated data and details of target vehicle construction and equipment are available in References

1, 2, and 3. The general configuration of the model M-34 vehicle is shown in Figure 1, which presents a right front view of vehicle used in the test firing program.

Versions of Target Vehicle Considered

Four versions of the basic model M-34 vehicle are considered in this report. All four versions are without a front winch; differences between versions are in items of equipment, such as radiator louvres, cab closure, and engine hood top and side panels, which provide protection to engine components from fragments approaching the vehicle from several aspects. The four versions are listed below with the differences noted. Version T_1 is the exsisting model M-34 vehicle; versions T_2, T_3, and T_4 are modified models.

Version T_1: basic vehicle - engine hood top and side panels of mild steel with thickness of 0.040 in., canvas tarpaulin cab closure, no radiator louvres.

Version T_2: same as version T_1 except that engine hood top and side panels have thickness of 0.060 in.

Version T_3: same as version T_1 except that engine hood top and side panels have thickness of 0.080 in.

Version T_4: similar to version T_3 with engine hood top and side panels of mild steel with thickness of 0.080 in., but also equipped with hard top cab closure of mild steel with thickness of 0.10 in., and with radiator louvres of mild steel with thickness of 0.080 in.

Presented Area of Target Vehicle

Values of vehicle presented area are presented in Figure 2 and

in Table V in this section. In Figure 2, vehicle presented area A_p is depicted as a function of aspect, i.e., of elevation angle θ and azimuth angle ϕ. In Table V are listed values of vehicle presented area A_p for selected aspects (paired values of θ and ϕ), values of vehicle presented area $\bar{A}_p$ (averaged over azimuth for selected values of θ), and a value of vehicle presented area $\bar{A}_p^*$, averaged over both azimuth and elevation. All values of vehicle presented area in Figure 2 and Table V are given in square feet (ft^2). Methods of averaging values of vehicle presented area are the same as those used in averaging values of vehicle vulnerable area. Details of averaging procedures are discussed in Section VI of Reference 5.

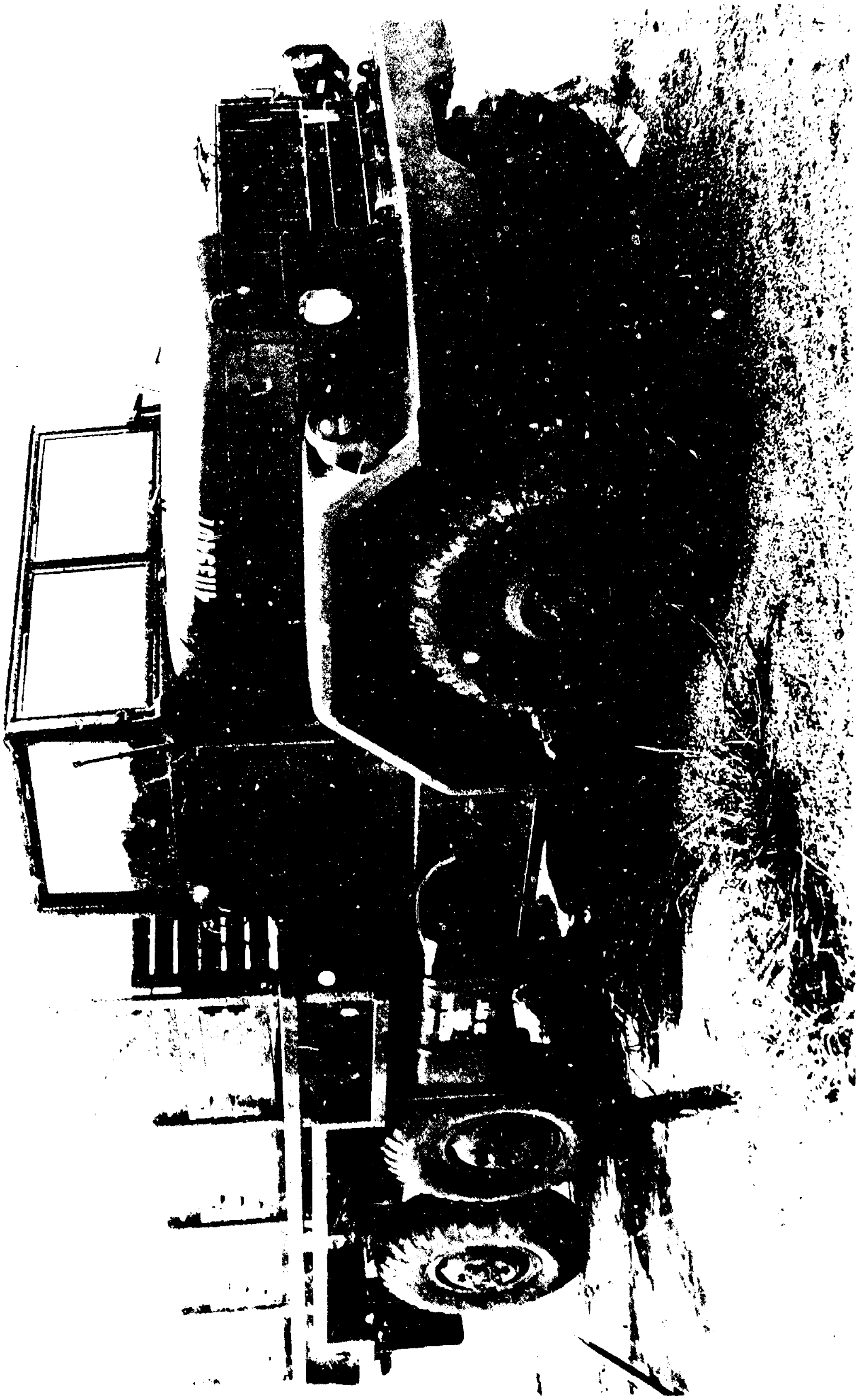

Figure 1. Right Front View of Model M-34 Vehicle Used in Test Firing Program

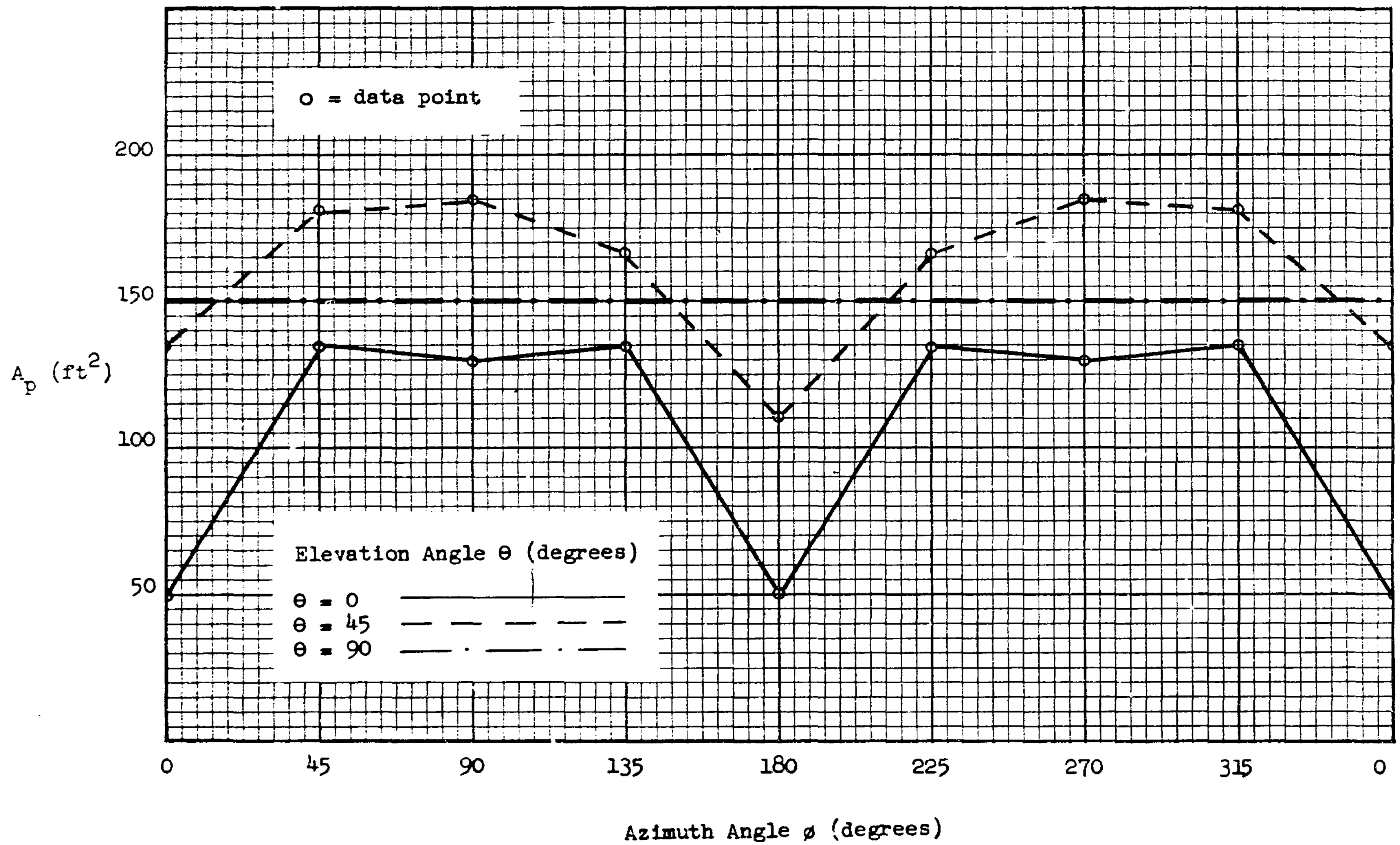

Figure 2. Presented Area A_p of Target Vehicle as a Function of Aspect

TABLE V

VEHICLE PRESENTED AREA A_p, $\bar{A}_p$, AND $\bar{A}_p^*$ FOR SELECTED NON-NEGATIVE ELEVATION ANGLES

θ	ø	A_p	θ	ø	A_p
0	0	50.92	45	0	136.15
	45	134.44		45	183.47
	90	132.03		90	185.88
	135	135.88		135	167.74
	180	50.92		180	114.29
	225	134.44		225	167.74
	270	132.03		270	185.88
	315	135.88		315	183.47
			90	-	150.02

θ	$\bar{A}_p$
0	113.31
45	165.57
90	150.02

$\bar{A}_p^*$
144.37

θ = elevation angle (degrees)

ø = azimuth angle (degrees)

A_p = vehicle presented area, for a given aspect, (ft^2)

$\bar{A}_p$ = vehicle presented area, averaged over azimuth for a given elevation angle θ, (ft^2)

$\bar{A}_p^*$ = vehicle presented area, averaged over azimuth and elevation, (ft^2)

SECTION II

(CONFIDENTIAL) ASSUMPTIONS AND DEFINITIONS

In the preceding section of this report, the target vehicle is described. Values of vulnerable area of this vehicle, which are associated with the several versions of the vehicle and with various combinations of fragment impact weight and velocity or with one or the other of the two shaped charges considered, are presented in Section IV. In this section, the assumptions employed in obtaining the values of vulnerable area are described. Hereafter, the target vehicle will be referred to simply as the vehicle.

A three dimensional, right handed, rectangular, Cartesian coordinate system (Figure 3) is employed as a frame of reference in the vehicle vulnerability discussion. In this system, the x-system, the vehicle is centered at the origin. The x_1x_2-plane is parallel to the ground plane; the x_1-axis is parallel to the longitudinal axis of the vehicle and is positive in the direction of forward motion of the vehicle; the x_3-axis is directed positively upward.

The term "projectile" is used generally to refer either to the fragments or shaped charge jets considered where the text does not require distinguishing between them. The only projectiles considered in this study are ones which hit the vehicle.

The "terminal trajectory" of a projectile is defined to be the tangent to the projectile trajectory at the point of impact on the vehicle. Viewed from a point on the positive x_3-axis, the angle (measured clockwise

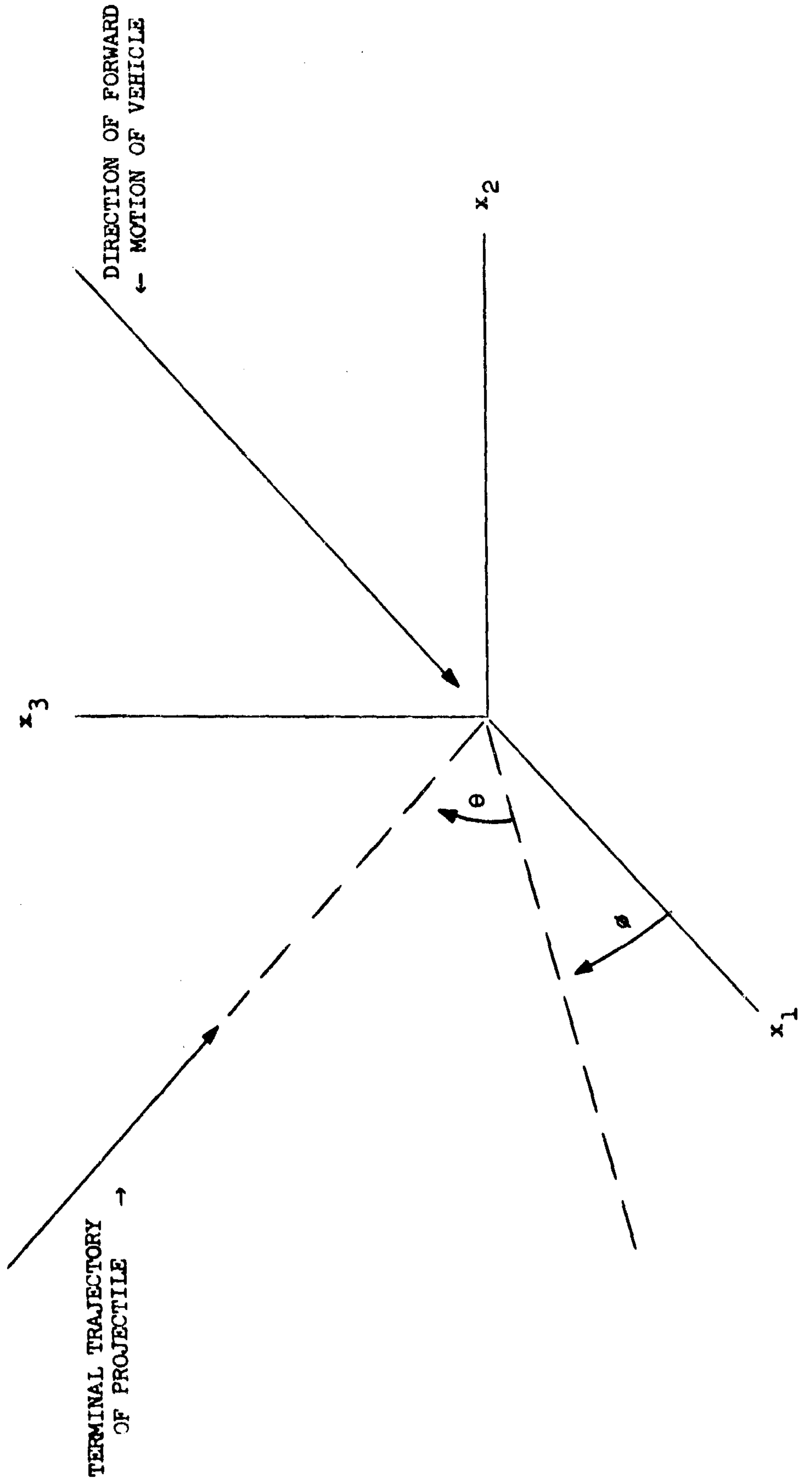

Figure 3. Coordinate System for Vehicle Vulnerability Study

from the positive x_1-axis) in the x_1x_2-plane between the x_1-axis and the projection of the terminal trajectory of the projectile in the x_1x_2-plane is the azimuth angle ϕ. The elevation angle θ is the acute angle (measured positively upward from the x_1x_2-plane) between the terminal trajectory of the projectile and the projection of this terminal trajectory in the x_1x_2-plane. Both θ and ϕ are expressed in degrees. Each different pair (θ, ϕ) of elevation and azimuth angles defines a unique "aspect" or orientation of the terminal trajectory of a projectile relative to the vehicle. For the shaped charge projectiles, each different pair (θ, ϕ) defines a unique orientation of the axis of the shaped charge jet relative to the vehicle.

The diameter, expressed in inches, of a shaped charge is denoted by the symbol d_j; $j = 1, 2$ refers to a particular projectile of the two considered. The term "velocity", or "impact velocity", refers to the velocity of a fragment at the moment of impact on the outer surface of the vehicle, i.e., at the moment of impact on the hood top, hood side panels, body panels, wheels, etc. Impact velocity is denoted by the symbol v; values of v are expressed in feet per second (fps). Impact velocity is not considered here as a parameter for shaped charges. The term "weight", or "impact weight", refers to the weight of a fragment prior to impact on the outer surface of the vehicle. Impact weight is denoted by the symbol w; values of w are expressed in grains (gr). Impact weight is not considered here as a parameter for shaped charges.

Four versions of the vehicle are considered. A particular version is denoted by the symbol T_i, $i = 1, 2, 3, 4$. The differences among versions are noted in Section I.

For a given set of parameter values, (θ, d_j) for shaped charges (which are considered only against vehicle version T_1) or (T_1, θ, w, v) for fragments, the value of vehicle vulnerable area averaged over azimuth only is denoted by the symbol $\bar{A}_v$. For a given set of parameter values, (d_j) for shaped charges or (T_1, w, v) for fragments, the value of vehicle vulnerable area averaged over both azimuth and elevation is denoted by the symbol $\bar{A}_v^*$. Values of vehicle presented area associated with a given aspect (θ, ϕ), averaged over azimuth for a given elevation, and averaged over both azimuth and elevation are denoted, respectively, by the symbols A_p, $\bar{A}_p$, and $\bar{A}_p^*$. Values of vehicle vulnerable area and of vehicle presented area are expressed in square feet (ft^2).

The estimates of vulnerable area presented in Section IV are based on the assumption that only certain components (hereafter called "vulnerable components") of the electrical, fuel, lubricating, and cooling systems of the vehicle contribute to the vulnerable area of the vehicle. It is assumed that the vehicle payload, if any, does not contribute to vehicle vulnerability and that the driver is immediately replaceable.

The preliminary portion of the vehicle vulnerability study reported herein was devoted to determining the location and masking for each of the vulnerable components of the vehicle. The model M-34 vehicle (basic version T_1) was available for inspection at APG, and measurements and estimates were made from direct observation. Estimates of component vulnerability to fragments are based on interpolation and extrapolation from component data obtained in previous vulnerability studies (References 4 and 5; Bibliography item 2) and on component data supplied by the Lansing Division of the White Motor Corporation, manufacturers of the Reo OA-331 engine employed in the

vehicle. Estimates of component vulnerability to shaped charge jets are based on the above mentioned data and on the results of a limited experimental firing program which is described in Section III.

The conditions under which the vehicle is assumed to be operating at the time of enemy attack, i.e., at the time of projectile (fragment or shaped charge jet) impact on the vehicle, and under which the vehicle is considered killed are outlined below:

1. the vehicle is travelling during daylight, under good weather conditions, along a level, improved road at a cruising speed of approximately 40 mph.

2. the destination of the vehicle is approximately one hour's travel time at normal speed from the point of engagement by the enemy.

3. projectile impact is assumed to occur at the instant the vehicle is engaged by the enemy.

4. the vehicle has a regulation supply of tools and repair equipment, is in a well maintained mechanical condition, and has over half a tank of fuel.

5. the driver of the vehicle is adequately trained for his duties and will exert all of his skill in efforts to keep the vehicle moving toward its destination. Furthermore, unless forced to do so by a serious fuel fire, he will not abandon the vehicle while it is capable of forward motion.

6. the vehicle is considered killed in a particular "mobility" kill category if:

a. the damage resulting from fragment impact or from shaped charge jet impact forces the vehicle to stop within a given time limit, dependent upon the kill category, providing that, after being forced to stop,

the vehicle cannot be repaired sufficiently, on the spot and within a five minute interval, to permit it to proceed to its destination at a speed of not less than 15 mph, or if

b. the damage results in a serious fuel fire which causes abandonment of the vehicle within a given time limit.

The fragments considered are compact steel fragments with hardness, on the Rockwell scale, between C35 and C38. Fragments with impact weight w less than 5 grains are not considered since available experimental data indicate that a single fragment of such impact weight cannot kill the vehicle in either of the kill categories, defined below, considered in this study. The two shaped charges considered (described more fully in Section IV) are of 1.0 and 1.8 inch diameter. Projectile impact damage, i.e., damage from fragment or shaped charge jet impact, to a vulnerable component of the vehicle may result in a kill of the vehicle in one of two categories, A or B, or in a failure to kill in either category. To be assessed, under assumption 6 above, as an A kill, projectile impact damage must cause the vehicle to stop within five minutes; similarly, to be assessed as a B kill, the damage must cause the vehicle to stop within forty minutes. On the average, damage resulting in an A kill causes the vehicle to stop within two minutes and damage resulting in a B kill causes the vehicle to stop within twenty minutes. Consequently, it is usual to refer to an A kill as a "two-minute" kill and a B kill as a "twenty-minute" kill. In any case where doubt exists as to appropriate assessment of kill category, the vehicle is given the benefit of the doubt.

The components of the vehicle which are assumed capable of contributing to vehicle vulnerable area, in the present study, under the definition of the A kill category are the following components of the electrical

and fuel systems:

1. distributor
2. ignition coil
3. timing gear
4. electrical wiring (includes ignition wiring only; does not include wiring to auxiliaries, such as to lights, horn, etc.)
5. voltage regulator
6. carburetor
7. fuel pump
8. fuel lines
9. fuel tank (with respect to shaped charge only)

The components of the vehicle which are assumed capable of contributing to vehicle vulnerable area under the definition of the B kill category are each of the first eight components listed above and, in addition, the fuel tank, with different qualifications (as noted below), and the following components of the lubricating and cooling systems:

9. fuel tank (with respect to shaped charge or fragment)
10. oil pan
11. oil gallery
12. oil lines
13. oil filter
14. air compressor
15. water pump
16. water lines
17. water jacket
18. radiator

The foregoing list of eighteen vulnerable components does not include the fuel filter. The fuel filter of the model M-34 vehicle is located in the fuel tank, and, generally, the fuel filter contribution to vehicle vulnerable area is included in the fuel tank contribution.

The inclusion of the fuel tank as a vulnerable component under two different restrictions, depending on the category of kill involved, arises from the following assumptions. It is assumed that the fuel tank can contribute to vehicle vulnerable area under the definition of A kill only if projectile impact damage results in a serious fuel fire satisfying A kill criteria. The experimental firing program (Section III) has shown that the shaped charge jet has the capability of causing such a fire; previous vehicle vulnerability investigations, such as those detailed in Reference 4, have shown that a fragment does not have such capability. With respect to B kills, the fuel tank can contribute to vehicle vulnerable area if projectile impact causes a serious fire consistent with B kill criteria or if leakage from fragment impact causes the vehicle to stop within the B kill time limit. The shaped charge jet is capable of causing such a fire, and a single hit by one of the larger fragments considered is capable of causing sufficient leakage to produce a B kill on the vehicle.

Neither the battery nor the generator is included as a vulnerable component. These components are so situated on the vehicle that a kill of both as a result of single projectile impact is very unlikely, and the vehicle can operate on either one long enough to exclude the possibility of either an A or B kill.

In the present study, the vehicle is assumed to be singly vulnerable with respect to components. Cumulative damage is not considered, i.e., vehicle damage resulting from a hit on the target by a given projectile is independent of damage resulting from a hit by any other projectile.

SECTION III

(CONFIDENTIAL) SHAPED CHARGE EXPERIMENTAL FIRING PROGRAM

This section presents a description of an experimental firing program designed to provide basic component vulnerability data for engine components of the basic version of the model M-34 vehicle relative to small shaped charges. A description of the observed damage to the vehicle and an assessment of kill probability dependent on the extent of this damage is included for each shaped charge fired. Although the shaped charges used in the experimental program are not properly classified as "rounds", the word "round" is frequently used in this section for ease of exposition.

The shaped charge firings against the vehicle were conducted by personnel of the Weapons Systems Laboratory (BRL) at Aberdeen Proving Grounds. Plans for round placement relative to target components were furnished by BAL representatives. The BAL representatives assisted in the firing program, recorded the apparent damage produced by each round, and made an assessment of the effect of the damage upon the ability of the vehicle to continue to operate for a given period of time subsequent to infliction of the damage.

Two sizes of shaped charges were considered. One has a cone diameter of 1.8 inches, a length of 3.25 inches, and a complete weight (charge plus liner) of 0.54 pounds with charge (Comp. B) weight of 0.42 pounds; the other has a cone diameter of 1.0 inches, a length of 1.0 inches, and a complete weight of 0.08 pounds with charge (Comp. B) weight of 0.06 pounds. Both of these shaped charges have smooth, conical, copper liners with apex angle of 45 degrees.

In the experimental program, eleven of the larger diameter shaped charge rounds were fired against selected components of the basic

version T_1 (described in Section I) of the vehicle, and eleven of the smaller diameter shaped charge rounds were fired against selected components of a second, identical vehicle. The shaped charge rounds used were bare; i.e., were not encased in metal or any casing which could fragment and thereby cause spall damage to the vehicle or its components; they were detonated statically, i.e., not in motion but in fixed position relative to the vehicle; and they were fired singly. Each round was positioned so that the standoff distance, measured along the extended cone axis from the base of the cone to the outer surface of the vehicle, was approximately 1.5 cone diameters. Furthermore, each round was so positioned that the damage inflicted by it would not be confused with damage caused by rounds previously fired against the same vehicle The engine of the vehicle was not running during any of the firings.

Following is a round-by-round description of the effects of the twenty-two rounds fired against the target, i.e., the vehicle. The date of firing is given for the first round in each of two sets of eleven rounds. Also included among the data for each round are:

1. the position of the round relative to the target. This is given in terms of aspect (θ, ϕ) and also in terms of the particular component toward which the jet was directed.

2. the obliquity angle, or the angle between the axis of the shaped charge jet and the normal to the target surface at the point of jet impact.

3. the observed results; i.e., damage to component(s), approximate diameter of holes in damaged components, distances of jet travel from point of impact on target surface to apparent point of greatest penetration into target, apparent cause of damage (jet, jet slug, spall from target surface, or blast). The jet slug was not found in any case, and, consequently,

component damage which may have been caused by the jet or by the jet slug is ascribed to the jet.

4. an assessment of the category of mobility kill (A or B) applicable to the observed component damage.

Rounds 1 through 11 are associated with the 1.8-inch diameter shaped charge.

Round 1. 5 May 1966

position: aspect (90, -); left, rear portion of hood, approximately 9 inches forward of windshield; to fire through hood, at an obliquity angle of 8 degrees, and into upper end of voltage regulator.

results: jet - perforated hood, making a 0.75 inch diameter hole; travelled 3 inches; perforated voltage regulator (9 inches through), destroying it completely; travelled 5 inches; severed generator lead cable; travelled 50 inches; penetrated 10 inches into packed gravel beneath vehicle, making a 0.75 inch diameter hole.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - shattered left half of windshield and cracked right half; caved in cowling along base of windshield for about 4 feet; blew instrument cluster panel loose from dashboard mounting; bent steering wheel badly.

assessment: mobility kill (A Category) due to destruction of voltage regulator by jet; no mobility kill due to blast damage to instrument cluster (wiring was not severed) or due to damage to steering wheel (vehicle still maneuverable); high probability of personnel kill on any or all occupants of cab.

Round 2.

postition: aspect (45, 0); right, forward portion of hood; to fire through hood, at an obliquity angle of 37 degrees, and into forward portion of carburetor.

results: jet - perforated hood (See blast, below, for hole size.); travelled 9 inches; perforated carburetor (3 inches through), making 1.0 inch diameter entry and exit holes; travelled 18 inches; nicked starter mechanism; travelled 5 inches; penetrated into exhaust pipe, making a 1.0 inch diameter entry hole; apparently expended in exhaust pipe.

: spall - hood spall amounting to several (4 or 5) small pieces with estimated weight, each, of 2 to 5 grains embedded in main fuel line and in air compressor; several large, flat pieces of hood spall also present in engine compartment.

: blast - tore a petalled, roughly elliptical, 24.0 by 12.0 inch hole in hood; severed copper water line from water pump to air compressor water jacket.

assessment: mobility kill (A Category) due to jet damage to carburetor; mobility kill (A Category) due to spall damage to main fuel line; mobility kill (B Category) due to blast severance of water line; insignificant damage to air compressor.

Round 3.

position: aspect (90, -); center, forward portion of hood; to fire through hood, at an obliquity angle of 8 degrees, and into rocker arm cover, approximately above number 2 cylinder.

results: jet - perforated hood, making a 1.0 by 0.75 inch hole; travelled 8 inches; perforated rocker arm cover, making a 1.0

inch diameter hole; travelled 3 inches; perforated cylinder head, making a 1.0 inch diameter hole; travelled 4 inches; perforated piston head, making a 1.0 inch diameter hole; (a 1.0 by 2.0 inch hole apparently caused by jet or spall, was noted in cylinder sleeve and wall immediately above piston head); travelled 18 inches; perforated bottom of oil pan, making a 1.5 inch diameter hole; travelled 32 inches; penetrated 2.0 inches into packed gravel beneath vehicle, making a 2.0 inch diameter hole.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (B Category) due to jet damage to oil pan; mobility kill (B Category) due to jet (or spall) damage to cylinder wall - this latter damage amounted to perforation of wall of water jacket aroung number 2 cylinder.

Round 4.

position: aspect (45, 0); right, extreme front portion of hood, just above radiator; to fire through hood, at an obliquity angle of 0 degrees, through radiator, and into air compressor water jacket.

results: jet - perforated hood, making a 0.5 by 0.75 inch hole; perforated radiator core (4 inches through), making a 0.75 inch diameter hole; travelled 7 inches; made a 1.5 by 0.6 inch nick in top of air compressor pulley; travelled 2 inches; penetrated into air compressor water jacket, making a 1.0 inch diameter entry hole; apparently expended in air compressor water jacket.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (B Category) due to jet damage to radiator core; mobility kill (B Category) due to jet damage to air compressor water jacket.

Round 5.

position: aspect (0, 270); left hand hood side panel, forward portion; to fire through hood side panel, at an obliquity angle of 8 degrees, and into side of generator.

results: jet - perforated hood side panel, making a 1.75 by 0.75 inch hole; travelled 13 inches; penetrated 1.0 inches into generator, making a 0.5 inch diameter entry hole; apparently expended in generator.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - tore a petalled, 8.0 by 12.0 inch hole in fender; spall from fender penetrated into and caused deflation of left front tire.

assessment: no mobility kill in either A or B Category; jet damage to generator would not result in such a kill; blast - spall damage to tire would cause steering difficulty and reduce maximum speed attainable but would not result in a mobility kill in A or B Category.

Round 6.

position: aspect (0, 270); left hand hood side panel, lower middle portion; to fire through hood side panel, at an obliquity angle of 8 degrees, and into push rod cover.

results: jet - perforated hood side panel, making a

0.75 inch diameter hole; travelled 21 inches; perforated push rod cover, making a 1.0 by 0.5 inch hole; travelled 2.5 inches; penetrated 2 inches into top, left side of block at junction of block and head and in vicinity of a head bolt; damaged cylinder head gasket.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - tore a petalled 8.0 by 10.0 inch hole in fender; spall from fender penetrated into left front tire which was already deflated from previous round damage (Round 5, above).

assessment: mobility kill (B Category) due to jet damage to cylinder head gasket; although the jet from this round did not hit the water jacket, there is sufficient evidence of damage producing capability to predict a high probability of mobility kill (B Category) given a hit on the water jacket by the jet of a round similarly positioned; blast - spall damage to left front tire would cause deflation but would not result in a mobility kill in either A or B Category (cf. remarks under assessment for Round 5, above.).

Round 7.

position: aspect (45, 90); right hand hood side panel, upper middle portion; to fire through hood side panel, at an obliquity angle of 46 degrees, through fender extension (inside engine compartment), at an obliquity angle of 45 degrees, and into oil filter, at an obliquity angle of 60 degrees.

results: jet - perforated hood side panel, making a 1.0 inch diameter hole; travelled 7 inches; perforated fender extension, making a 1.0 inch by 0.75 inch hole; travelled 2 inches; perforated fender

skirt, making a 1.0 inch by 0.75 inch hole; travelled 6 inches; perforated oil filter (6 inches through), making a 0.5 by 3.0 inch entry and a 0.5 inch diameter exit hole; travelled 9 inches; perforated side wall of oil pan, making a 0.5 inch diameter hole; apparently expended in oil pan.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (B Category) due to jet damage to oil filter; mobility kill (B Category) due to jet damage to oil pan (note: the level at which the side wall of the oil pan is perforated is quite critical; jets parallel to the one described could perforate all of the same surfaces but culminate an inch or so higher on the side wall of the oil pan and, in such case, damage to the oil pan might not be assessable as a mobility kill (B Category).).

Round 8.

position: aspect (0, 135); right hand side cowling, upper portion; to fire through cowling, at an obliquity angle of 53 degrees, through fire wall, at an obliquity angle of 45 degrees, through air cleaner, and into carburetor float bowl.

results: jet - perforated cowling, making a 1.0 by 2.0 inch hole; travelled 3 inches; perforated fire wall, making a 1.0 inch diameter hole; travelled 1 inch; perforated air cleaner (7 inches through), making 1.0 by 2.0 inch entry and exit holes; travelled 13 inches; missed aim point (carburetor float bowl), but hit edge of mounting bracket attaching carburetor to intake manifold; sheared off portion of bolt plus a portion of bracket casting; apparently expended at bracket (but see under spall, below).

: spall - a 0.25 inch diameter hole in intake manifold in line with jet path apparently was caused by sheared off portion of bolt and bracket casting (See under jet, above.). The hole is approximately the size of the missing portion of bolt and casting and appears to be considerably smaller than what might have been expected from the jet itself. However, it is possible that all but a portion of the jet was interrupted at the impact point on the carburetor bracket, and that the uninterrupted portion of the jet continued on for 6 inches to make the hole in the manifold. No other spall capable of producing significant component damage was noted in the engine compartment.

: blast - tore a petalled, roughly square, 7.0 by 7.0 inch hole in cowling.

assessment: no mobility kill in either A or B Category however, there is sufficient evidence of damage-producing capability to predict a mobility kill (A Category) given a hit on the carburetor float bowl by the jet of a round similarly positioned.

Round 9.

position: aspect (45, 0); middle, to surface of fuel tank; to fire through top surface of fuel tank, at an obliquity angle of 45 degrees, and into tank filled to 80 percent capacity with military grade (80 octane) gasoline; ambient temperature approximately 60 degrees Fahrenheit; fuel tank removed from target vehicle.

results: jet - perforated tank surface; started serious fuel fire which would be uncontrollable with vehicle's normal fire fighting equipment and would undoubtedly cause immediate abandonment of vehicle.

assessment: mobility kill (A Category) due to uncontrollable (with normal vehicular equipment) fire which would cause immediate abandonment of vehicle; a fire of the magnitude resulting from this round would have a high probability of destroying cab, cargo, tires, and of severely damaging some of the mechanical portions of the vehicle.

Round 10.

position: aspect (45, 270); extreme left portion of hood, just above hood side panel and about midway between radiator and cowling; to fire through hood, at an obliquity angle of 0 degrees, and into top portion of distributor.

results: jet - perforated hood, making a 1.0 inch diameter hole; travelled 18 inches; perforated distributor (5 inches through), making a 1.0 by 2.0 inch entry and a 0.5 inch diameter exit hole; travelled 4 inches; perforated lower push rod inspection plate, making a 0.5 inch diameter hole; apparently expended in push rod region.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (A Category) due to jet damage to distributor; possible mobility kill (A Category) due to jet damage to ignition coil (extent of damage to coil not ascertained as kill certain due to damage to distributor) - a hit directly on the ignition coil would most certainly have resulted in such a mobility kill.

Round 11.

position: aspect (0, 135); under cargo bed in region of right rear quarter of rear-rear differential housing; to fire into rear-

rear differential housing, at an obliquity angle of 0 degrees.

results: jet - perforated differential housing (15 inches through), making a 0.75 inch diameter entry hole, making a 0.32 inch diameter hole through spider gear, and making a 0.5 inch diameter exit hole; no indication of continuation of jet path.

: spall - description not applicable.

: blast - no apparent blast damage.

assessment: no mobility kill in either A or B Category; vehicle was towed from test site to storage area at conclusion of this set of eleven firings - rear-rear wheels showed no tendency to lock - damage to differential was not significant.

Rounds 12 through 22 are associated with the 1.0-inch diameter shaped charge. For this set of firings, the target vehicle used for the previous set of firings was replaced by another model M-34 vehicle with undamaged engine and cab region. Several of the rounds in this latter set are positioned similarly to rounds of the former set, and, thus, some comparable data are available for the two different diameter shaped charge rounds considered. A special note of reference to any previous round of similar placement is included among the descriptive data.

Round 12. 2 June 1966

position: aspect (90, -); left, rear portion of hood, approximately 9 inches forward of windshield; to fire through hood, at an obliquity angle of 8 degrees, and into upper end of voltage regulator.

results: jet - perforated hood, making a roughly elliptical 0.25 by 0.37 inch hole; travelled 3 inches; penetrated voltage regulator to a depth of 8 inches, destroying current relay, current regulator,

and voltage regulator coils and severing connecting wiring; apparently expended in voltage regulator.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - caused multiple cracking of both left and right halves of windshield but did not blow out either section; no other apparent blast damage.

assessment: mobility kill (A Category) due to destruction of voltage regulator by jet.

note: effects of this round should be compared with those of Round 1 for which round placement is identical relative to target components.

Round 13.

position: aspect (90, -); center, forward portion of hood; to fire through hood, at an obliquity angle of 8 degrees, and into rocker arm cover, approximately above number 2 cylinder.

results: jet - perforated hood, making a roughly elliptical 0.25 by 0.37 inch hole; travelled 8 inches; perforated rocker arm cover, making a roughly elliptical 0.25 by 0.37 inch hole; travelled 1 inch; perforated upper side of rocker arm shaft, making a 0.2 inch diameter hole; apparently expended in rocker arm shaft.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: no mobility kill in either A or B Category.

note: effects of this round should be compared with those of Round 3 for which round placement is almost identical relative to target components.

Round 14.

position: aspect (45, 270); extreme left portion of hood, just above hood side panel and about midway between radiator and cowling; to fire through hood, at an obliquity angle of 0 degrees, and into top portion of distributor.

results: jet - perforated hood, making a 0.31 by 0.62 inch hole; travelled 18 inches; perforated distributor shielding, making a number of very small holes in the shielding in a strip 0.18 inches wide by 1.0 inches long; penetrated into coil, making several small holes; apparently expended in coil.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (A Category) due to jet damage to coil; jet damage to distributor not significant.

note: effects of this round should be compared with those of Round 10 for which round placement is identical relative to target components.

Round 15.

position: aspect (45, 90); extreme right portion of hood, just above hood side panel and about midway between radiator and cowling; to fire through hood, at an obliquity angle of 0 degrees, and into upper end of oil filter.

results: jet - perforated hood, making a 0.37 inch diameter hole; travelled 21 inches; perforated top of oil filter, making a 0.25 inch diameter hole and causing a longitudinal split in side wall of filter; apparently expended in oil filter.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (B Category) due to jet damage to oil filter.

note: effects of this round should be compared with those of Round 7 although round placement was not identical in both cases.

Round 16. 6 June 1966

position: aspect (45, 0); right side of center of hood, about midway between radiator and cowling; to fire through hood, at an obliquity angle of 37 degrees, and into carburetor float bowl.

results: jet - perforated hood, making a 0.75 inch diameter hole; travelled 7 inches; penetrated 0.37 inches into flange casting at point where air intake line from air cleaner enters carburetor.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: no mobility kill in either A or B Category; however, jet damage to flange casting gave sufficient evidence of damage or damage-producing capability to predict a mobility kill (A Category) given a hit on the carburetor float bowl by the jet of a round similarly positioned.

Round 17.

position: aspect (45, 0); as Round 16, above, but moved forward about 5 inches; to fire through hood, at an obliquity angle of 37 degrees, and into carburetor float bowl.

results: jet - perforated hood, making a 0.5 by 0.75 inch hole; travelled 7 inches; perforated one wall of intake manifold adjacent to carburetor, making a 0.25 inch diameter hole; apparently expended in intake manifold.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: no mobility kill in either A or B Category; however, jet damage to intake manifold gave sufficient evidence of damage producing capability to predict a mobility kill (A Category) given a hit on the carburetor float bowl by the jet of a round similarly positioned; compare assessment remarks with those of Round 16, above.

Round 18.

position: aspect (0, 0); upper, right, front portion of radiator; to fire through radiator, at an obliquity angle of 0 degrees, and into air compressor water jacket.

results: jet - perforated radiator (3.5 inches through), making a 1.0 inch diameter hole; travelled 3 inches; perforated a copper water line (0.4 inches through), making 0.25 inch diameter entry and exit holes; travelled 4 inches; perforated wall of air compressor water jacket making a 0.25 inch diameter hole; apparently expended in air compressor water jacket.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (B Category) due to jet damage to radiator; mobility kill (B Category) due to jet damage to copper water line; mobility kill (B Category) due to jet damage to air compressor water jacket.

Round 19.

position: aspect (0, 90); right hand hood side panel, upper, center portion; to fire through engine side panel, at an obliquity angle of 8 degrees, and into exhaust manifold.

results: jet - perforated hood side panel, making a 0.5 inch diameter hole; travelled 18 inches; perforated wall of exhaust manifold, making a 0.75 inch diameter hole; apparently expended in exhaust manifold.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: no mobility kill in either A or B Category.

Round 20.

position: aspect (0, 270); left hand fender skirt, upper portion, midway between radiator and firewall; to fire through fender skirt, at an obliquity angle of 0 degrees, through the steering column, and into the ignition coil.

results: jet - perforated fender skirt, making a

0.5 by 0.75 inch hole; travelled 2 inches; perforated steering gear shaft jacket, making a 0.25 inch diameter hole; travelled 0.25 inches; perforated steering gear shaft (1.12 inches through), making a 0.25 inch diameter hole; travelled 0.25 inches; perforated steering gear shaft jacket, making a 0.25 inch diameter hole; travelled 5 inches; perforated ignition coil housing, making a 0.25 inch hole; apparently expended in ignition coil.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: mobility kill (A Category) due to jet damage to ignition coil; no significant damage to steering mechanism; vehicle still capable of being steered.

Round 21.

position: aspect (not applicable); to fire through a protecting medium (a 0.25 inch, face hardened armor plate taken from a model M-16 half track vehicle was employed with rear face of armor toward jet), at an obliquity angle of 0 degrees, and into a fuel tank, partially filled with military grade (80 octane) gasoline, two inches below level of fuel surface; ambient temperature approximately 70 degrees Fahrenheit; fuel tank removed from vehicle.

results: jet - perforated face hardened armor plate, making a 0.37 inch diameter hole; travelled 4 inches; perforated fuel tank (22 inches through), making 0.25 inch entry and exit holes; started a serious fuel fire which would be uncontrollable with vehicle's normal fire fighting equipment and would undoubtedly cause immediate abandonment of vehicle.

assessment: mobility kill (A Category) due to uncontrollable (with normal vehicular equipment) fire which would cause immediate abandonment of vehicle; a fire of the magnitude resulting from this round would have a high probability of destroying cab, cargo, tires, and of severely damaging some of the mechanical portions of the vehicle.

note: effects of this round should be compared with those of Round 9 which was also fired into a fuel tank.

Round 22.

position: aspect (0, 135); right hand side cowling, upper portion; to fire through cowling, at an obliquity angle of 53 degrees, through fire wall at an obliquity angle of 45 degrees, through air cleaner, and into carburetor float bowl.

results: jet - perforated cowling, making a 0.25 by 1.5 inch hole; travelled 3 inches; perforated fire wall, making a 0.37 inch diameter hole; travelled 2 inches; perforated air cleaner mounting bracket (0.125 inches through) and air cleaner wall, making a 0.25 inch hole in each; apparently expended in air cleaner.

: spall - no spall capable of producing significant component damage noted in engine compartment.

: blast - no apparent blast damage.

assessment: no mobility kill in either A or B Category.

note: effects of this round should be compared with those of Round 8 for which round placement is identical relative to target components.

SECTION IV

(CONFIDENTIAL) RESULTS

The results of the investigation of the vulnerability of four versions (one basic version T_1 and three modified versions T_2, T_3, and T_4, described in Section I) of the model M-34 vehicle to single-shot fragment impacts are presented at the end of this section in Tables VI, VII, VIII, and IX, and in Figures 4 and 5. The results of the investigation of the vulnerability of the basic version T_1 of the vehicle to attack with single shaped charges are presented at the end of this section in Table X and in Figures 6, 7, 8, and 9.

For each of the four versions of the vehicle, comparable values of vehicle vulnerable area $\bar{A}_v$ (averaged over azimuth for selected values of elevation angle θ) and $\bar{A}_v^*$ (averaged over azimuth and elevation) associated with each mobility kill category (A and B) and with single-fragment impact are presented in Tables VI, VII, VIII, and IX. Values of $\bar{A}_v$ are presented in Table VI for A Category and in Table VII for B Category. Values of $\bar{A}_v^*$ are presented in Table VIII for A Category and in Table IX for B Category. In each of the four tables, values of vehicle vulnerable area are presented for 90 preselected combinations of fragment impact weight w and impact velocity v.

For the basic version T_1 of the vehicle and for each fragment impact weight w considered, graphs of the relationship between vehicle vulnerable area $\bar{A}_v^*$ and fragment impact velocity v are presented in Figures 4 (for mobility kill, A Category) and 5 (for mobility kill, B Category). On each graph, the solid line curve associated with a designated value of fragment impact weight w is a linear interpolation between data points established

at selected values of fragment impact velocity v. Data points exist for $v = 125, 250$; for values of v from $v = 500$ to $v = 4000$ in 500 fps increments; and for values of v from $v = 5000$ to $v = 10{,}000$ in 1000 fps increments. Note that in Figure 4 the curve $\bar{A}_v^* = 0$ is associated with $w = 5$ for all v.

In Figures 4 and 5, there are points and, in some cases, intervals where curves associated with two or more values of w (e.g., 1000 and 500 in Figure 4) coincide. To avoid unnecessary clutter, the value of w with which a given curve is associated is shown only once. Therefore, at bifurcation points of curves, if any doubt exists as to the value of w with which a given branch is associated, the following rule must be observed. Given a choice of two values of w to assign to either of two branches of a curve, always assign the larger value of w to the upper branch.

Presented in Table X, for the basic version T_1 of the vehicle, are values of vehicle vulnerable area $\bar{A}_v$ and $\bar{A}_v^*$ associated with shaped charges. For each of the two shaped charges considered, values of $\bar{A}_v$ are presented for mobility kill A Category and B Category and for three selected values (0, 45, and 90) of elevation angle Θ: a value of $\bar{A}_v^*$ is given for each of the mobility kill categories.

For the basic version T_1 of the vehicle, for each of the two shaped charges described in Section III, and for each of the two mobility kill categories (A and B), Figures 6, 7, 8, and 9 present vehicle vulnerable area A_v as a function of aspect, i.e., as a function of paired values (Θ, ϕ). Figures 6 (for mobility kill, A Category) and 7 (for mobility kill, B Category) relate to the 1.0-inch diameter shaped charge; Figures 8 (for mobility kill, A Category) and 9 (for mobility kill, B Category) relate to the

1.8-inch diameter shaped charge. The A_v curves in Figures 6, 7, 8, and 9 are linear interpolations between data points established, for a given value of elevation angle θ, at selected values (namely, 0, 45, 90, 135, 180, 225, 270, and 315) of azimuth angle ϕ.

Values of vehicle vulnerable area $\bar{A}_v$ and $\bar{A}_v^*$ presented in the tables at the end of this section and in the Summary and used in constructing the graphs presented herein are weighted averages. The methods employed in computing values of $\bar{A}_v$ and $\bar{A}_v^*$ are discussed in considerable detail in a subsection of Section VI of Reference 5.

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TABLE VI

VULNERABLE AREA $\bar{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
5	1000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

$\bar{A}_v$ = vulnerable area (ft^2) averaged over azimuth for indicated elevation angle θ (degrees).

T_i = vehicle version; i = 1 - basic vehicle, 0.040 in. mild steel hood, no louvres, no metal cab closure.

= 2 - same as T_1 except 0.060 in. mild steel hood.

= 3 - same as T_2 except 0.080 in. mild steel hood.

= 4 - same as T_3 but has 0.080 in. mild steel louvres and 0.10 in. mild steel cab closure.

w = fragment impact weight (grains).

v = fragment impact velocity (fps).

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TABLE VI (cont.)

VULNERABLE AREA $\overline{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
10	1000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	0.05	0.03	0.09	0.03	0.01	0.01	0.03	0.01	0.00	0.02	0.00	0.00
	3000	0.08	0.08	0.14	0.07	0.04	0.10	0.05	0.02	0.08	0.03	0.01	0.08
	4000	0.10	0.11	0.17	0.09	0.09	0.14	0.07	0.06	0.12	0.06	0.04	0.12
	5000	0.11	0.11	0.21	0.08	0.02	0.19	0.05	0.02	0.00	0.03	0.00	0.00
	6000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	1000	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
	2000	0.06	0.04	0.12	0.04	0.02	0.04	0.04	0.01	0.01	0.02	0.00	0.01
	3000	0.11	0.12	0.19	0.09	0.08	0.16	0.07	0.04	0.12	0.06	0.02	0.12
	4000	0.12	0.15	0.22	0.11	0.13	0.19	0.10	0.10	0.17	0.09	0.07	0.17
	5000	0.13	0.17	0.24	0.12	0.14	0.23	0.11	0.12	0.19	0.09	0.10	0.19
	6000	0.14	0.19	0.29	0.13	0.16	0.27	0.12	0.12	0.24	0.10	0.09	0.24
	7000	0.13	0.09	0.30	0.04	0.02	0.00	0.04	0.02	0.00	0.02	0.00	0.00
	8000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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TABLE VI (cont.)

VULNERABLE AREA $\bar{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
30	1000	0.02	0.01	0.02	0.02	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00
	2000	0.11	0.12	0.20	0.08	0.06	0.16	0.06	0.03	0.08	0.04	0.01	0.08
	3000	0.16	0.21	0.28	0.15	0.17	0.27	0.13	0.13	0.23	0.11	0.09	0.23
	4000	0.17	0.23	0.33	0.17	0.22	0.31	0.16	0.20	0.29	0.15	0.17	0.29
	5000	0.16	0.24	0.33	0.16	0.22	0.31	0.16	0.21	0.30	0.15	0.18	0.30
	6000	0.16	0.24	0.33	0.16	0.23	0.31	0.15	0.21	0.30	0.15	0.18	0.30
	7000	0.16	0.24	0.32	0.16	0.23	0.32	0.15	0.22	0.31	0.13	0.18	0.31
	8000	0.15	0.22	0.31	0.15	0.21	0.31	0.14	0.16	0.31	0.12	0.13	0.31
	9000	0.14	0.18	0.31	0.10	0.03	0.31	0.06	0.03	0.00	0.03	0.00	0.00
	10000	0.00	0.03	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00
60	1000	0.04	0.03	0.06	0.03	0.01	0.02	0.03	0.01	0.00	0.02	0.00	0.00
	2000	0.15	0.18	0.26	0.13	0.13	0.23	0.11	0.08	0.20	0.09	0.05	0.20
	3000	0.20	0.27	0.32	0.19	0.25	0.32	0.18	0.22	0.31	0.17	0.17	0.31
	4000	0.22	0.30	0.34	0.21	0.29	0.34	0.21	0.28	0.33	0.20	0.23	0.33
	5000	0.22	0.30	0.34	0.22	0.29	0.34	0.21	0.29	0.34	0.19	0.24	0.34
	6000	0.21	0.29	0.34	0.20	0.28	0.34	0.20	0.28	0.34	0.18	0.24	0.34
	7000	0.19	0.27	0.34	0.19	0.27	0.34	0.19	0.26	0.34	0.17	0.23	0.34
	8000	0.17	0.25	0.34	0.17	0.25	0.33	0.17	0.24	0.33	0.14	0.20	0.33
	9000	0.17	0.24	0.33	0.16	0.24	0.32	0.16	0.23	0.32	0.13	0.19	0.32
	10000	0.16	0.22	0.32	0.15	0.16	0.31	0.10	0.03	0.31	0.08	0.00	0.31

(CONFIDENTIAL) TABLE VI (cont.)

VULNERABLE AREA $\bar{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

w	v	T_1 θ=0	T_1 θ=45	T_1 θ=90	T_2 θ=0	T_2 θ=45	T_2 θ=90	T_3 θ=0	T_3 θ=45	T_3 θ=90	T_4 θ=0	T_4 θ=45	T_4 θ=90
120	1000	0.07	0.07	0.14	0.05	0.03	0.07	0.04	0.02	0.03	0.03	0.00	0.03
	2000	0.20	0.25	0.30	0.18	0.22	0.28	0.17	0.18	0.26	0.14	0.13	0.26
	3000	0.23	0.32	0.33	0.23	0.31	0.33	0.22	0.29	0.33	0.21	0.24	0.33
	4000	0.25	0.33	0.35	0.25	0.32	0.35	0.24	0.32	0.35	0.23	0.27	0.35
	5000	0.25	0.33	0.36	0.25	0.32	0.35	0.25	0.32	0.35	0.23	0.29	0.35
	6000	0.25	0.32	0.36	0.25	0.32	0.36	0.25	0.32	0.36	0.23	0.28	0.36
	7000	0.24	0.32	0.36	0.24	0.32	0.36	0.24	0.31	0.35	0.21	0.26	0.35
	8000	0.23	0.31	0.35	0.23	0.31	0.35	0.22	0.30	0.34	0.19	0.24	0.34
	9000	0.21	0.29	0.34	0.20	0.28	0.34	0.20	0.28	0.34	0.18	0.23	0.34
	10000	0.19	0.26	0.34	0.18	0.26	0.34	0.17	0.25	0.33	0.14	0.19	0.33
240	1000	0.13	0.14	0.21	0.10	0.08	0.17	0.08	0.05	0.11	0.06	0.01	0.11
	2000	0.26	0.34	0.34	0.25	0.31	0.33	0.24	0.29	0.31	0.21	0.21	0.31
	3000	0.29	0.39	0.37	0.29	0.39	0.36	0.29	0.38	0.35	0.28	0.31	0.35
	4000	0.31	0.40	0.40	0.30	0.40	0.40	0.30	0.39	0.39	0.29	0.35	0.39
	5000	0.31	0.40	0.40	0.31	0.39	0.40	0.31	0.39	0.39	0.30	0.35	0.39
	6000	0.30	0.38	0.39	0.30	0.38	0.39	0.30	0.38	0.38	0.28	0.34	0.38
	7000	0.29	0.37	0.39	0.29	0.36	0.38	0.28	0.36	0.38	0.27	0.32	0.38
	8000	0.27	0.35	0.38	0.27	0.34	0.38	0.26	0.34	0.38	0.24	0.28	0.38
	9000	0.26	0.33	0.38	0.25	0.33	0.37	0.25	0.33	0.36	0.21	0.27	0.36
	10000	0.23	0.32	0.35	0.22	0.31	0.34	0.22	0.30	0.34	0.20	0.24	0.34

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TABLE VI (cont.)

VULNERABLE AREA $\bar{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
500	1000	0.22	0.25	0.27	0.19	0.20	0.25	0.16	0.13	0.26	0.13	0.07	0.26
	2000	0.29	0.39	0.40	0.29	0.39	0.39	0.29	0.38	0.39	0.28	0.30	0.39
	3000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.38	0.41
	4000	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41	0.31	0.39	0.41
	5000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41
	6000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.39	0.41
	7000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.37	0.41
	8000	0.31	0.40	0.41	0.31	0.40	0.40	0.31	0.40	0.40	0.30	0.36	0.40
	9000	0.31	0.40	0.40	0.31	0.39	0.39	0.31	0.39	0.39	0.30	0.34	0.39
	10000	0.30	0.39	0.39	0.30	0.38	0.38	0.29	0.37	0.38	0.25	0.29	0.38
1000	1000	0.27	0.33	0.33	0.26	0.31	0.30	0.24	0.29	0.29	0.21	0.19	0.29
	2000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.30	0.38	0.41
	3000	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41
	4000	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41
	5000	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41
	6000	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41	0.32	0.40	0.41
	7000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41
	8000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.39	0.41
	9000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.37	0.41
	10000	0.31	0.40	0.41	0.31	0.40	0.41	0.31	0.40	0.41	0.30	0.35	0.41

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TABLE VII

VULNERABLE AREA $\bar{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
5	1000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	2000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	3000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	4000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	5000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	6000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	7000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	8000	0.76	0.44	0.00	0.7[illegible]	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	9000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00
	10000	0.76	0.44	0.00	0.76	0.44	0.00	0.76	0.44	0.00	0.00	0.00	0.00

$\bar{A}_v$ = vulnerable area (ft^2) averaged over azimuth for indicated elevation angle θ (degrees).

T_i = vehicle version; i = 1 - basic vehicle, 0.040 in. mild steel hood, no louvres, no metal cab closure.

= 2 - same as T_1 except 0.060 in. mild steel hood.

= 3 - same as T_2 except 0.080 in. mild steel hood.

= 4 - same as T_3 but has 0.080 in. mild steel louvres and 0.10 in. mild steel cab closure.

w = fragment impact weight (grains).

v = fragment impact velocity (fps).

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TABLE VII (cont.)

VULNERABLE AREA $\overline{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
10	1000	0.78	0.44	0.00	0.78	0.44	0.00	0.78	0.44	0.00	0.02	0.00	0.00
	2000	1.08	1.08	0.68	0.93	0.48	0.53	0.85	0.45	0.17	0.22	0.00	0.17
	3000	1.38	1.54	1.02	1.33	1.32	0.78	1.01	0.72	0.65	0.74	0.34	0.65
	4000	1.48	1.80	1.27	1.43	1.58	1.05	1.39	1.41	0.92	1.39	1.14	0.92
	5000	1.24	1.17	1.61	1.12	0.49	1.44	0.94	0.49	0.00	0.18	0.02	0.00
	6000	0.78	0.44	0.00	0.78	0.44	0.00	0.78	0.44	0.00	0.02	0.00	0.00
	7000	0.78	0.44	0.00	0.78	0.44	0.00	0.78	0.44	0.00	0.02	0.00	0.00
	8000	0.78	0.44	0.00	0.78	0.44	0.00	0.78	0.44	0.00	0.02	0.00	0.00
	9000	0.78	0.44	0.00	0.78	0.44	0.00	0.78	0.44	0.00	0.02	0.00	0.00
	10000	0.78	0.44	0.00	0.78	0.44	0.00	0.78	0.44	0.00	0.02	0.00	0.00
15	1000	0.83	0.44	0.14	0.81	0.44	0.00	0.81	0.44	0.00	0.05	0.00	0.00
	2000	1.39	1.46	0.83	1.07	0.72	0.62	0.99	0.47	0.52	0.54	0.02	0.52
	3000	1.52	1.89	1.26	1.46	1.58	1.08	1.12	1.02	0.85	1.12	0.74	0.85
	4000	1.63	2.04	1.51	1.57	1.91	1.31	1.53	1.63	1.20	1.53	1.45	1.20
	5000	1.69	2.11	1.71	1.66	1.95	1.62	1.61	1.85	1.43	1.61	1.79	1.43
	6000	1.70	2.13	1.88	1.67	1.94	1.81	1.30	1.19	1.69	1.30	0.89	1.69
	7000	1.24	0.91	1.91	0.89	0.48	0.00	0.89	0.48	0.00	0.13	0.00	0.00
	8000	0.80	0.44	0.00	0.80	0.44	0.00	0.80	0.44	0.00	0.04	0.00	0.00
	9000	0.80	0.44	0.00	0.80	0.44	0.00	0.80	0.44	0.00	0.04	0.00	0.00
	10000	0.80	0.44	0.00	0.80	0.44	0.00	0.80	0.44	0.00	0.04	0.00	0.00

TABLE VII (cont.)

VULNERABLE AREA $\overline{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
30	1000	1.01	0.48	0.53	0.89	0.44	0.02	0.89	0.44	0.00	0.13	0.00	0.00
	2000	1.60	1.91	1.25	1.37	1.35	1.04	1.20	0.75	0.76	0.80	0.30	0.76
	3000	1.84	2.65	1.80	1.76	2.22	1.71	1.69	1.90	1.49	1.69	1.60	1.49
	4000	2.02	2.90	2.03	1.97	2.76	1.94	1.90	2.45	1.85	1.90	2.35	1.85
	5000	2.19	2.94	2.05	2.12	2.77	2.00	2.06	2.59	1.93	2.01	2.45	1.93
	6000	2.18	2.82	2.03	2.12	2.66	2.00	2.06	2.51	1.95	2.01	2.37	1.95
	7000	1.95	2.59	1.99	1.91	2.42	1.97	1.86	2.33	1.94	1.86	2.21	1.94
	8000	1.83	2.34	1.98	1.78	2.14	1.95	1.37	1.35	1.93	1.37	1.02	1.93
	9000	1.36	1.79	1.97	1.21	0.51	1.96	0.99	0.51	0.00	0.23	0.03	0.00
	10000	0.80	0.48	0.00	0.80	0.48	0.00	0.80	0.48	0.00	0.04	0.00	0.00
60	1000	1.10	0.77	0.01	0.99	0.45	0.40	0.91	0.45	0.01	0.16	0.00	0.01
	2000	1.84	2.52	1.74	1.75	2.05	1.50	1.49	1.50	1.27	1.49	1.19	1.27
	3000	2.17	3.10	2.02	2.10	2.95	2.00	2.04	2.50	1.98	2.04	2.37	1.98
	4000	2.52	3.36	2.10	2.47	3.25	2.07	2.41	3.16	2.05	2.37	2.99	2.05
	5000	2.55	3.44	2.10	2.53	3.40	2.10	2.50	3.32	2.10	2.50	3.16	2.10
	6000	2.69	3.42	2.10	2.68	3.39	2.10	2.67	3.35	2.10	2.61	3.19	2.10
	7000	2.47	3.39	2.09	2.46	3.36	2.09	2.45	3.30	2.09	2.41	3.12	2.09
	8000	2.34	3.28	2.09	2.30	3.04	2.09	2.23	2.88	2.06	2.23	2.65	2.06
	9000	2.16	2.84	2.07	2.07	2.61	2.04	2.00	2.36	2.02	2.00	1.92	2.02
	10000	1.92	2.34	2.02	1.43	1.43	1.98	1.27	0.59	1.96	0.82	0.03	1.96

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TABLE VII (cont.)

VULNERABLE AREA $\overline{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
120	1000	1.47	1.46	1.01	1.21	0.68	0.63	1.12	0.52	0.40	0.59	0.06	0.40
	2000	2.20	3.00	2.03	2.08	2.61	1.95	1.98	2.28	1.81	1.98	2.00	1.81
	3000	2.58	3.43	2.09	2.55	3.35	2.09	2.51	3.25	2.08	2.47	3.09	2.08
	4000	2.69	3.54	2.10	2.67	3.51	2.10	2.65	3.45	2.10	2.64	3.33	2.10
	5000	3.04	3.55	2.10	3.04	3.54	2.10	3.03	3.52	2.10	2.98	3.43	2.10
	6000	3.02	3.53	2.10	3.01	3.52	2.10	3.00	3.51	2.10	2.97	3.43	2.10
	7000	2.97	3.49	2.10	2.97	3.49	2.10	2.96	3.48	2.10	2.96	3.41	2.10
	8000	2.57	3.42	2.10	2.57	3.42	2.10	2.56	3.41	2.10	2.56	3.26	2.10
	9000	2.49	3.40	2.10	2.49	3.38	2.10	2.48	3.30	2.10	2.44	3.10	2.10
	10000	2.37	3.31	2.10	2.33	3.04	2.09	2.27	2.61	2.09	2.27	2.40	2.09
240	1000	1.78	2.02	1.57	1.47	1.19	1.27	1.30	0.71	0.70	0.89	0.23	0.70
	2000	2.58	3.42	2.08	2.51	3.26	2.07	2.42	2.91	2.04	2.42	2.74	2.04
	3000	2.80	3.63	2.09	2.78	3.60	2.09	2.76	3.55	2.09	2.76	3.45	2.09
	4000	3.23	3.73	2.10	3.21	3.70	2.10	3.20	3.67	2.10	3.15	3.60	2.10
	5000	3.23	3.73	2.10	3.22	3.72	2.10	3.22	3.70	2.10	3.22	3.66	2.10
	6000	3.46	3.71	2.10	3.46	3.70	2.10	3.45	3.69	2.10	3.45	3.66	2.10
	7000	3.41	3.67	2.10	3.41	3.66	2.10	3.40	3.65	2.10	3.40	3.63	2.10
	8000	3.05	3.52	2.10	3.04	3.52	2.10	3.04	3.52	2.10	3.04	3.49	2.10
	9000	2.67	3.44	2.10	2.67	3.44	2.10	2.66	3.44	2.10	2.61	3.34	2.10
	10000	2.53	3.43	2.10	2.53	3.42	2.10	2.53	3.40	2.10	2.48	3.20	2.10

(CONFIDENTIAL)

TABLE VII (cont.)

VULNERABLE AREA $\bar{A}_v$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

		T_1			T_2			T_3			T_4		
w	v	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90	θ=0	θ=45	θ=90
500	1000	2.28	2.84	1.97	2.09	2.17	1.93	1.74	1.43	1.61	1.74	1.03	1.61
	2000	2.85	3.67	2.10	2.83	3.62	2.10	2.81	3.54	2.10	2.76	3.45	2.10
	3000	3.30	3.76	2.10	3.30	3.75	2.10	3.30	3.73	2.10	3.24	3.67	2.10
	4000	3.43	3.78	2.10	3.43	3.78	2.10	3.43	3.78	2.10	3.43	3.77	2.10
	5000	3.67	3.78	2.10	3.67	3.78	2.10	3.67	3.78	2.10	3.67	3.78	2.10
	6000	3.68	3.81	2.10	3.68	3.81	2.10	3.68	3.81	2.10	3.68	3.80	2.10
	7000	3.61	3.77	2.10	3.61	3.77	2.10	3.62	3.77	2.10	3.62	3.76	2.10
	8000	3.57	3.76	2.10	3.57	3.75	2.10	3.57	3.75	2.10	3.57	3.74	2.10
	9000	3.10	3.56	2.10	3.10	3.56	2.10	3.10	3.56	2.10	3.10	3.54	2.10
	10000	3.04	3.50	2.10	3.03	3.49	2.10	3.03	3.48	2.10	2.97	3.42	2.10
1000	1000	2.55	3.36	2.01	2.45	2.95	2.02	2.35	2.43	2.00	2.35	2.05	2.00
	2000	2.95	3.75	2.10	2.95	3.72	2.10	2.95	3.70	2.10	2.93	3.64	2.10
	3000	3.32	3.78	2.10	3.32	3.78	2.10	3.32	3.78	2.10	3.32	3.78	2.10
	4000	3.71	3.79	2.10	3.71	3.79	2.10	3.71	3.79	2.10	3.71	3.79	2.10
	5000	3.71	3.84	2.10	3.71	3.84	2.10	3.71	3.84	2.10	3.71	3.84	2.10
	6000	3.71	3.83	2.10	3.71	3.83	2.10	3.71	3.83	2.10	3.71	3.83	2.10
	7000	3.68	3.80	2.10	3.69	3.81	2.10	3.70	3.82	2.10	3.70	3.82	2.10
	8000	3.63	3.77	2.10	3.63	3.77	2.10	3.63	3.77	2.10	3.63	3.77	2.10
	9000	3.55	3.60	2.10	3.55	3.60	2.10	3.55	3.60	2.10	3.55	3.59	2.10
	10000	3.12	3.57	2.10	3.12	3.57	2.10	3.11	3.57	2.10	3.11	3.55	2.10

(CONFIDENTIAL) TABLE VIII

VULNERABLE AREA $\bar{A}_v^*$ OF VEHICLE ASSOCIATED
WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

w	v	T_1	T_2	T_3	T_4
5	1000	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.00	0.00
	3000	0.00	0.00	0.00	0.00
	4000	0.00	0.00	0.00	0.00
	5000	0.00	0.00	0.00	0.00
	6000	0.00	0.00	0.00	0.00
	7000	0.00	0.00	0.00	0.00
	8000	0.00	0.00	0.00	0.00
	9000	0.00	0.00	0.00	0.00
	10000	0.00	0.00	0.00	0.00
10	1000	0.00	0.00	0.00	0.00
	2000	0.04	0.02	0.02	0.01
	3000	0.09	0.06	0.04	0.02
	4000	0.11	0.09	0.07	0.05
	5000	0.12	0.05	0.03	0.01
	6000	0.00	0.00	0.00	0.00
	7000	0.00	0.00	0.00	0.00
	8000	0.00	0.00	0.00	0.00
	9000	0.00	0.00	0.00	0.00
	10000	0.00	0.00	0.00	0.00
15	1000	0.01	0.01	0.01	0.00
	2000	0.06	0.03	0.02	0.01
	3000	0.12	0.09	0.06	0.04
	4000	0.14	0.13	0.10	0.09
	5000	0.16	0.14	0.12	0.10
	6000	0.18	0.16	0.13	0.11
	7000	0.12	0.03	0.03	0.01
	8000	0.00	0.00	0.00	0.00
	9000	0.00	0.00	0.00	0.00
	10000	0.00	0.00	0.00	0.00

$\bar{A}_v^*$ = vulnerable area (ft^2) averaged over azimuth and elevation.

w = fragment impact weight (grains).

v = fragment impact velocity (fps).

T_i = vehicle version; i = 1 - basic vehicle, 0.040 in. mild steel hood, no louvres, no metal cab closure.

= 2 - same as T_1 except 0.060 in. mild steel hood.

= 3 - same as T_2 except 0.080 in. mild steel hood.

= 4 - same as T_3 but has 0.080 in. mild steel louvres and 0.10 in. mild steel cab closure.

(CONFIDENTIAL) TABLE VIII (cont.)

VULNERABLE AREA $\bar{A}_v^*$ OF VEHICLE ASSOCIATED
WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

W	V	T_1	T_2	T_3	T_4
30	1000	0.01	0.01	0.01	0.00
	2000	0.12	0.08	0.05	0.03
	3000	0.20	0.17	0.14	0.11
	4000	0.22	0.21	0.19	0.17
	5000	0.22	0.21	0.19	0.18
	6000	0.22	0.21	0.20	0.18
	7000	0.21	0.21	0.20	0.17
	8000	0.20	0.20	0.16	0.14
	9000	0.18	0.08	0.04	0.01
	10000	0.01	0.01	0.01	0.00
60	1000	0.03	0.02	0.01	0.01
	2000	0.17	0.14	0.10	0.07
	3000	0.24	0.23	0.21	0.18
	4000	0.27	0.26	0.26	0.23
	5000	0.27	0.27	0.26	0.23
	6000	0.26	0.26	0.25	0.22
	7000	0.24	0.24	0.24	0.21
	8000	0.23	0.22	0.22	0.18
	9000	0.22	0.22	0.21	0.18
	10000	0.20	0.17	0.08	0.05
120	1000	0.08	0.04	0.03	0.01
	2000	0.23	0.21	0.18	0.14
	3000	0.29	0.28	0.27	0.23
	4000	0.30	0.30	0.29	0.26
	5000	0.30	0.30	0.30	0.27
	6000	0.30	0.30	0.29	0.27
	7000	0.29	0.29	0.29	0.25
	8000	0.28	0.28	0.27	0.23
	9000	0.26	0.26	0.25	0.22
	10000	0.24	0.23	0.23	0.18

(CONFIDENTIAL) TABLE VIII (cont.)

VULNERABLE AREA $\bar{A}_v^*$ OF VEHICLE ASSOCIATED
WITH FRAGMENT IMPACT (MOBILITY KILL : A CATEGORY) : (U)

w	v	T_1	T_2	T_3	T_4
240	1000	0.14	0.10	0.06	0.04
	2000	0.31	0.29	0.27	0.22
	3000	0.35	0.35	0.34	0.30
	4000	0.36	0.36	0.36	0.33
	5000	0.36	0.36	0.36	0.33
	6000	0.35	0.35	0.35	0.32
	7000	0.34	0.33	0.33	0.31
	8000	0.32	0.32	0.31	0.28
	9000	0.31	0.30	0.30	0.25
	10000	0.28	0.28	0.27	0.23
500	1000	0.24	0.20	0.15	0.11
	2000	0.36	0.35	0.34	0.30
	3000	0.36	0.36	0.36	0.35
	4000	0.37	0.37	0.37	0.36
	5000	0.37	0.37	0.37	0.36
	6000	0.37	0.37	0.37	0.36
	7000	0.37	0.37	0.37	0.35
	8000	0.36	0.36	0.36	0.34
	9000	0.36	0.36	0.36	0.33
	10000	0.36	0.35	0.34	0.28
1000	1000	0.31	0.29	0.27	0.20
	2000	0.36	0.36	0.36	0.35
	3000	0.37	0.37	0.37	0.37
	4000	0.37	0.37	0.37	0.37
	5000	0.[illegible]	0.37	0.37	0.37
	6000	0.37	0.37	0.37	0.37
	7000	0.37	0.37	0.37	0.37
	8000	0.37	0.37	0.37	0.36
	9000	0.37	0.37	0.37	0.35
	10000	0.37	0.37	0.36	0.34

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TABLE IX

VULNERABLE AREA $\bar{A}_v^*$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

w	v	T_1	T_2	T_3	T_4
5	1000	0.53	0.53	0.53	0.00
	2000	0.53	0.53	0.53	0.00
	3000	0.53	0.53	0.53	0.00
	4000	0.53	0.53	0.53	0.00
	5000	0.53	0.53	0.53	0.00
	6000	0.53	0.53	0.53	0.00
	7000	0.53	0.53	0.53	0.00
	8000	0.53	0.53	0.53	0.00
	9000	0.53	0.53	0.53	0.00
	10000	0.53	0.53	0.53	0.00
10	1000	0.54	0.54	0.54	0.01
	2000	1.05	0.66	0.58	0.10
	3000	1.44	1.28	0.83	0.51
	4000	1.64	1.48	1.37	1.22
	5000	1.23	0.81	0.63	0.08
	6000	0.54	0.54	0.54	0.01
	7000	0.54	0.54	0.54	0.01
	8000	0.54	0.54	0.54	0.01
	9000	0.54	0.54	0.54	0.01
	10000	0.54	0.54	0.54	0.01
15	1000	0.57	0.55	0.55	0.02
	2000	1.39	0.85	0.68	0.26
	3000	1.70	1.49	1.05	0.90
	4000	1.84	1.74	1.56	1.46
	5000	1.92	1.81	1.72	1.70
	6000	1.94	1.83	1.27	1.11
	7000	1.11	0.60	0.60	0.05
	8000	0.54	0.54	0.54	0.02
	9000	0.54	0.54	0.54	0.02
	10000	0.54	0.54	0.54	0.02

$\bar{A}_v^*$ = vulnerable area (ft^2) averaged over azimuth and elevation.

w = fragment impact weight (grains).

v = fragment impact velocity (fps).

T_i = vehicle version; i = 1 - basic vehicle, 0.040 in. mild steel hood, no louvres, no metal cab closure.

= 2 - same as T_1 except 0.060 in. mild steel hood.

= 3 - same as T_2 except 0.080 in. mild steel hood.

= 4 - same as T_3 but has 0.080 in. mild steel louvres and 0.10 in. mild steel cab closure.

(CONFIDENTIAL) TABLE IX (cont.)

VULNERABLE AREA $\bar{A}_v^*$ OF VEHICLE ASSOCIATED
WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

w	v	T_1	T_2	T_3	T_4
30	1000	0.68	0.58	0.58	0.05
	2000	1.74	1.33	0.92	0.53
	3000	2.28	2.00	1.79	1.62
	4000	2.50	2.39	2.19	2.14
	5000	2.59	2.46	2.33	2.24
	6000	2.51	2.41	2.29	2.20
	7000	2.30	2.19	2.12	2.05
	8000	2.12	1.99	1.40	1.22
	9000	1.64	0.89	0.66	0.10
	10000	0.57	0.57	0.57	0.02
60	1000	0.89	0.65	0.59	0.06
	2000	2.20	1.90	1.48	1.31
	3000	2.66	2.55	2.28	2.21
	4000	2.95	2.86	2.79	2.68
	5000	3.00	2.97	2.92	2.82
	6000	3.04	3.02	2.99	2.89
	7000	2.93	2.92	2.89	2.77
	8000	2.83	2.68	2.57	2.44
	9000	2.52	2.36	2.19	1.96
	10000	2.16	1.47	0.95	0.48
120	1000	1.43	0.88	0.74	0.29
	2000	2.62	2.36	2.13	1.98
	3000	3.00	2.95	2.88	2.78
	4000	3.10	3.08	3.04	2.97
	5000	3.25	3.24	3.23	3.16
	6000	3.23	3.22	3.21	3.15
	7000	3.19	3.18	3.18	3.14
	8000	2.99	2.99	2.99	2.90
	9000	2.95	2.94	2.89	2.77
	10000	2.86	2.70	2.44	2.33

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TABLE IX (cont.)

VULNERABLE AREA $\bar{A}_v^*$ OF VEHICLE ASSOCIATED WITH FRAGMENT IMPACT (MOBILITY KILL : B CATEGORY) : (U)

w	v	T_1	T_2	T_3	T_4
240	1000	1.89	1.30	0.93	0.52
	2000	3.00	2.88	2.66	2.56
	3000	3.19	3.17	3.14	3.08
	4000	3.41	3.39	3.37	3.31
	5000	3.41	3.41	3.40	3.37
	6000	3.49	3.49	3.48	3.46
	7000	3.45	3.45	3.44	3.43
	8000	3.23	3.23	3.23	3.21
	9000	3.05	3.04	3.04	2.97
	10000	2.98	2.98	2.97	2.84
500	1000	2.56	2.12	1.56	1.35
	2000	3.24	3.20	3.15	3.08
	3000	3.46	3.45	3.44	3.39
	4000	3.52	3.52	3.52	3.52
	5000	3.61	3.61	3.61	3.61
	6000	3.63	3.63	3.63	3.63
	7000	3.58	3.58	3.58	3.58
	8000	3.56	3.56	3.56	3.55
	9000	3.28	3.27	3.27	3.27
	10000	3.22	3.21	3.20	3.15
1000	1000	2.95	2.68	2.37	2.16
	2000	~~3.32~~	3.31	3.29	3.25
	3000	3.48	3.48	3.48	3.47
	4000	3.63	3.63	3.63	3.63
	5000	3.66	3.66	3.66	3.66
	6000	3.65	3.65	3.65	3.65
	7000	3.64	3.64	3.64	3.64
	8000	3.59	3.59	3.59	3.59
	9000	3.47	3.47	3.47	3.46
	10000	3.29	3.28	3.28	3.27

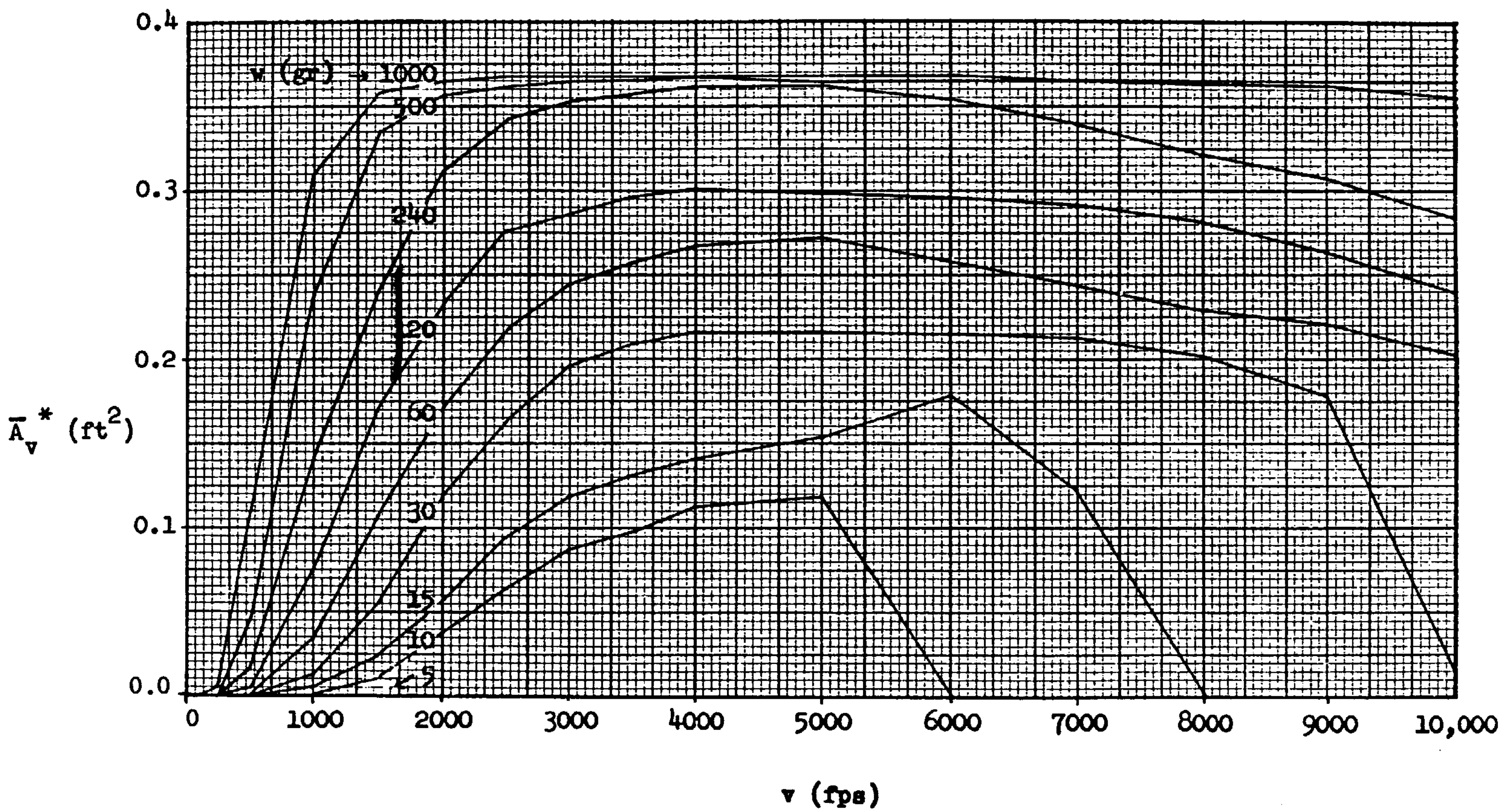

Figure 4. (CONFIDENTIAL) Vulnerable Area $\bar{A}_v^*$, for Basic Version T_1 of Target Vehicle, vs Fragment Impact Velocity v for Selected Fragment Weight w (Mobility Kill : A Category); (U)

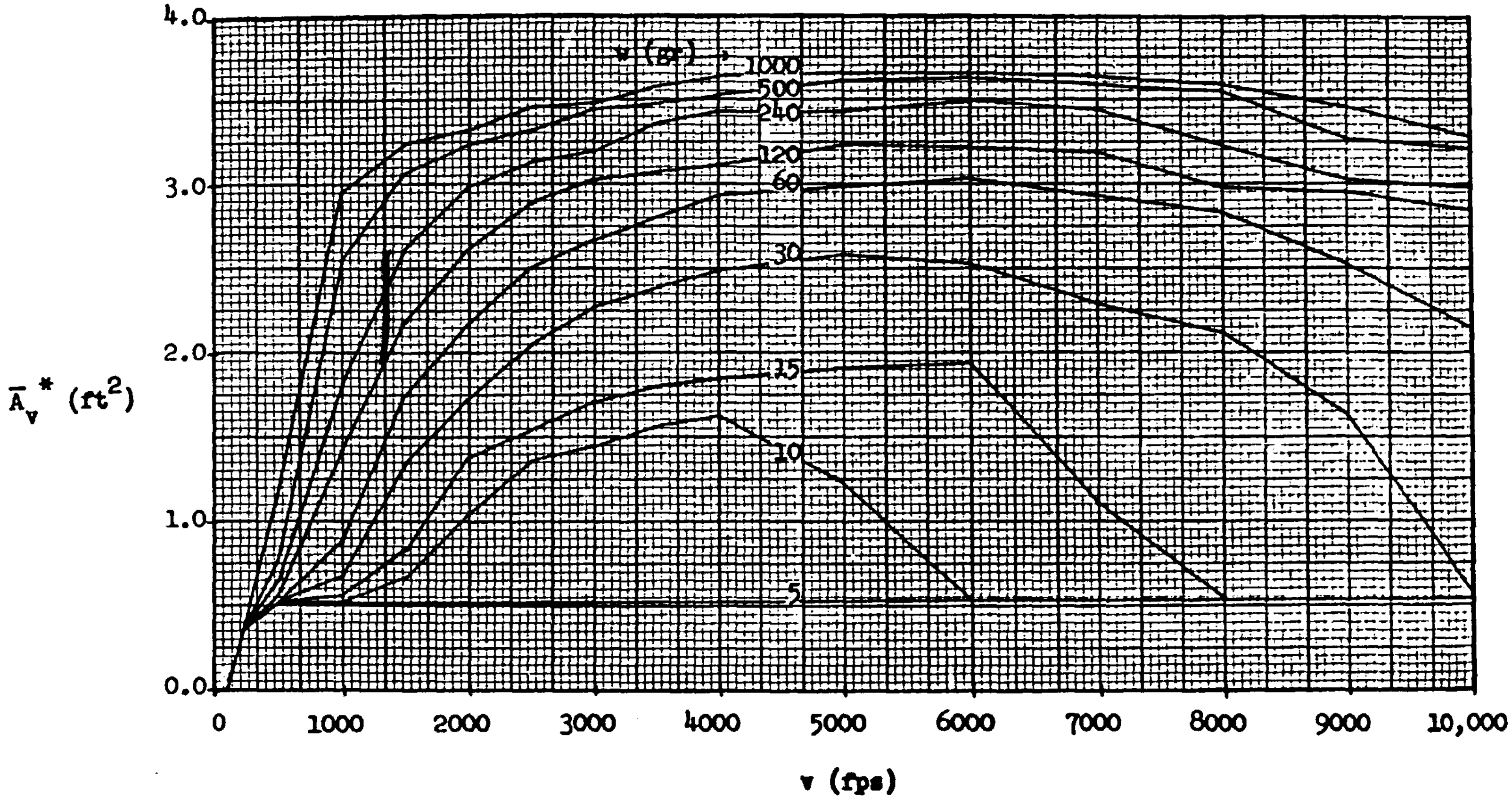

Figure 5. (CONFIDENTIAL) Vulnerable Area $\bar{A}_v^*$, for Basic Version T_1 of Target Vehicle, vs Fragment Impact Velocity v for Selected Fragment Weight w (Mobility Kill : B Category); (U)

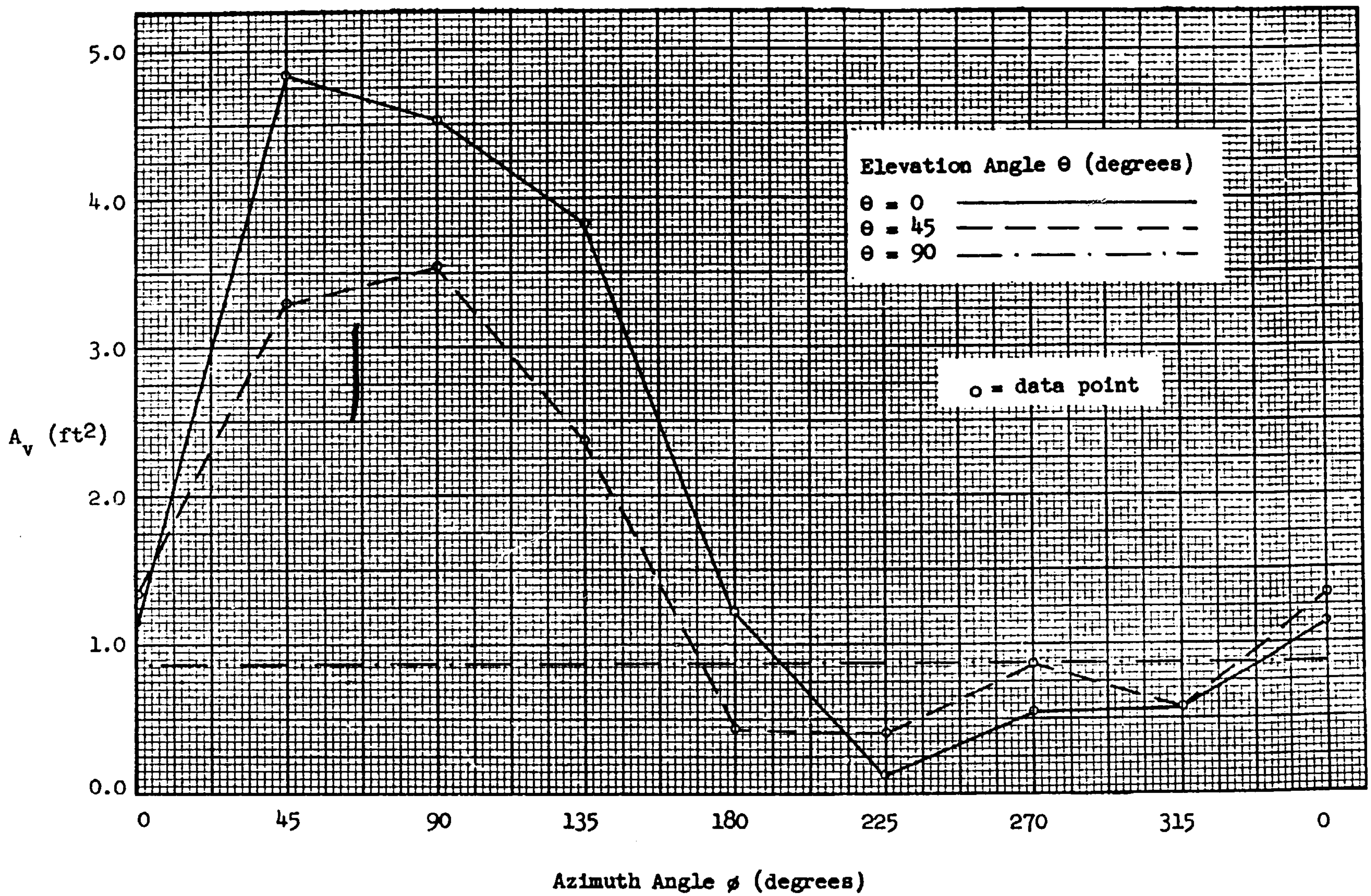

Figure 6. (CONFIDENTIAL) Vulnerable Area A_v, for Basic Version T_1 of Target Vehicle, as a Function of Aspect Relative to 1.0-inch Diameter Shaped Charge (Mobility Kill : A Category) : (U)

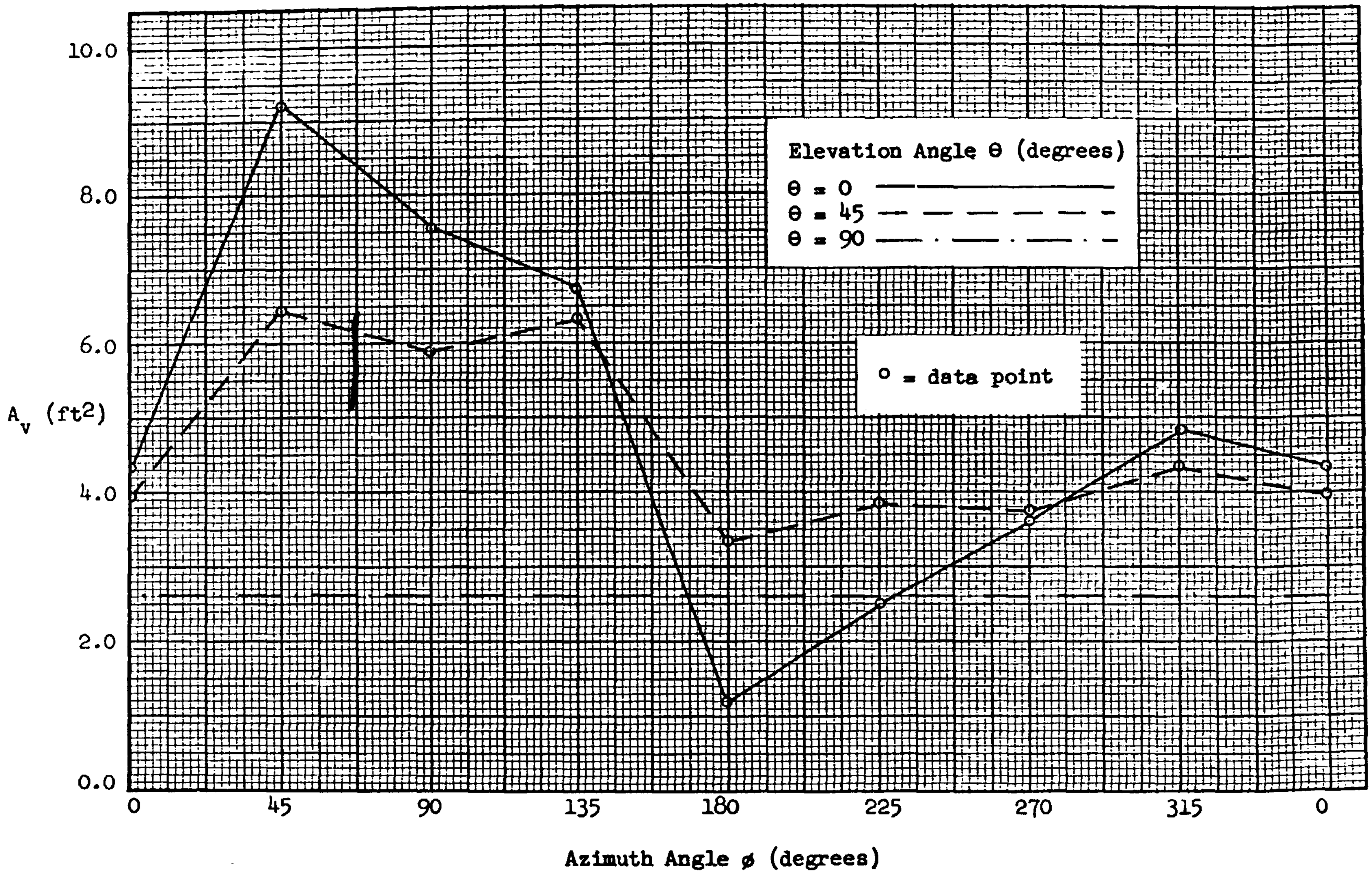

Figure 7. (CONFIDENTIAL) Vulnerable Area A_v, for Basic Version T_1 of Target Vehicle, as a Function of Aspect Relative to 1.0-inch Diameter Shaped Charge (Mobility Kill : B Category) : (U)

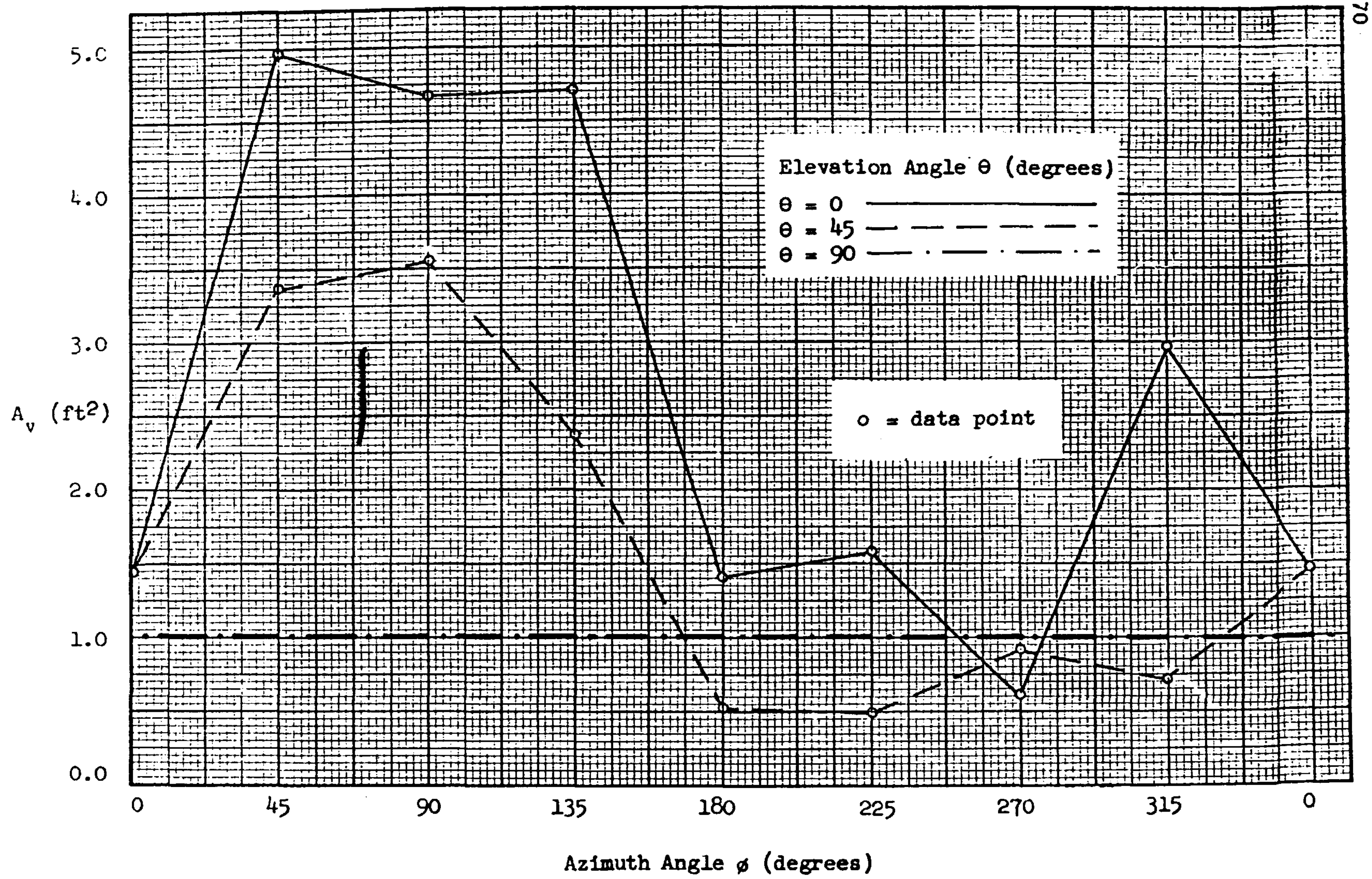

Figure 8. (CONFIDENTIAL) Vulnerable Area A_v, for Basic Version T_1 of Target Vehicle, as a Function of Aspect Relative to 1.8-inch Diameter Shaped Charge (Mobility Kill : A Category) : (U)

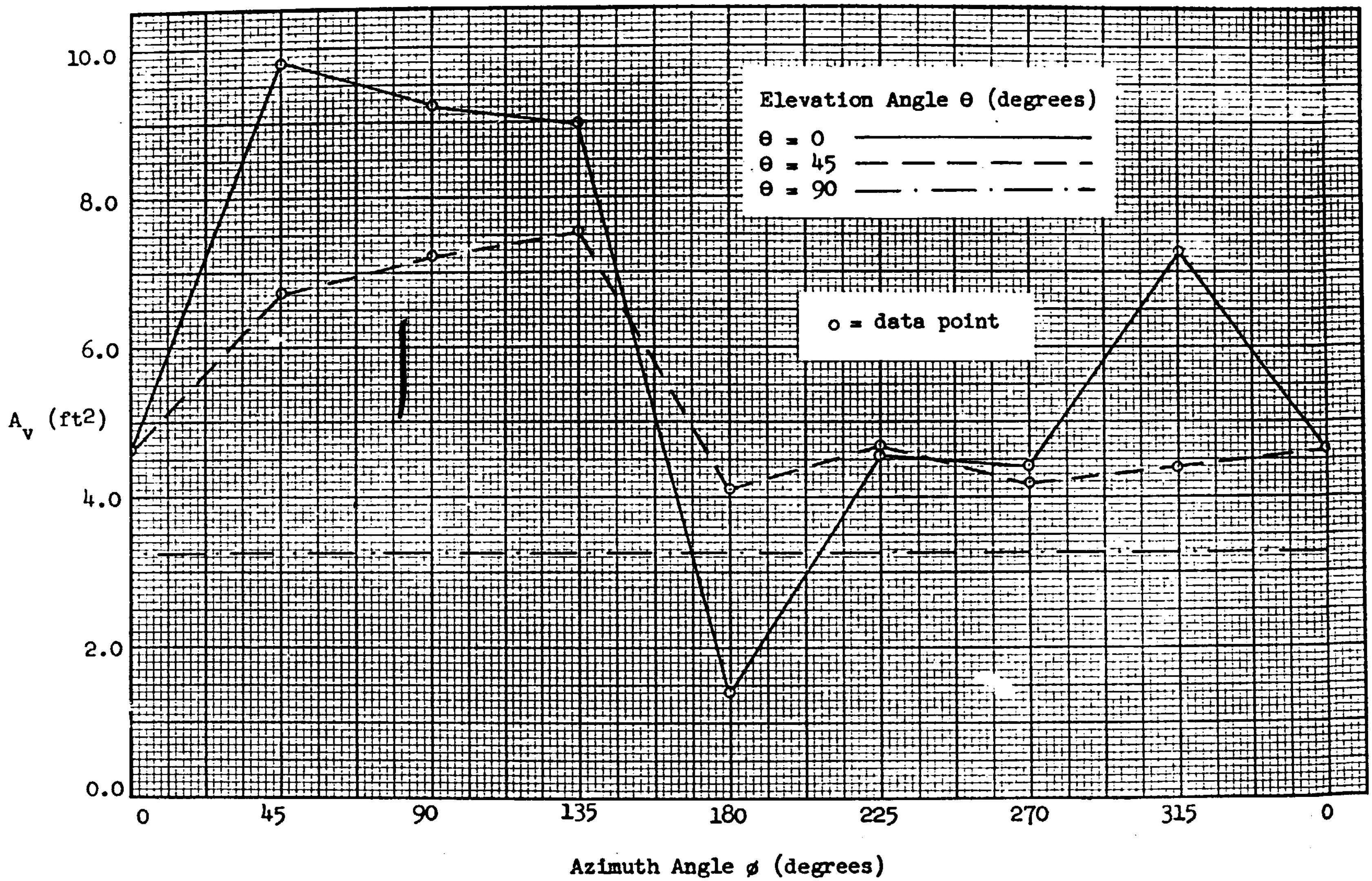

Figure 9. (CONFIDENTIAL) Vulnerable Area A_v, for Basic Version T_1 of Target Vehicle, as a Function of Aspect Relative to 1.8-inch Diameter Shaped Charge (Mobility Kill : B Category) : (U)

(CONFIDENTIAL) TABLE X

VULNERABLE AREA $\bar{A}_v$ AND $\bar{A}_v^*$ ASSOCIATED WITH SHAPED CHARGES FOR BASIC VERSION T_1 OF TARGET VEHICLE : (U)

Mobility Kill Category	d	θ	$\bar{A}_v$	$\bar{A}_v^*$
A	1.0	0	2.11	--
		45	1.62	--
		90	0.86	--
		--	--	1.75
	1.8	0	2.81	--
		45	1.67	--
		90	1.00	--
		--	--	2.05
B	1.0	0	5.01	--
		45	4.74	--
		90	2.62	--
		--	--	4.68
	1.8	0	6.30	--
		45	5.44	--
		90	3.28	--
		--	--	5.60

d = shaped charge diameter (inches).

$\bar{A}_v$ = vulnerable area (ft^2) averaged over azimuth for indicated elevation angle θ (degrees).

$\bar{A}_v^*$ = vulnerable area (ft^2) averaged over azimuth and elevation.

Note: the entry -- in a data column indicates that the column designation, θ, $\bar{A}_v$, or $\bar{A}_v^*$ is not applicable.

SECTION V

(CONFIDENTIAL) CONCLUSIONS AND COMMENTS

The vulnerability data presented in this report apply specifically to the model M-34 vehicle and are dependent on strict application of the assumptions and definitions of Section II. Some specific conclusions resulting from the investigation of the vulnerability of the vehicle to the fragments and to the shaped charges considered and comments on the use of the vulnerability data generated during the investigation are presented in this section.

Applicability of Vulnerability Data

With certain limitations, the values of averaged vulnerability data, i.e., the values of $\bar{A}_v$ and of $\bar{A}_v^*$, presented in the tables and graphs in the Summary and in Section IV are considered to be applicable to vehicles other than the target vehicle. The criteria which are suggested for determining the applicability of vulnerability data to vehicles other than the one for which the data are generated are discussed at length in Reference 6.

As noted in Section I, and consistent with the reservations cited above, most of the vulnerability data generated for the model M-34 vehicle and presented her~~ein are~~ considered directly applicable to some twenty-three other vehicles (listed in Section I) with identical engines, power trains, etc. In addition, the averaged vulnerability data (particularly the values of $\bar{A}_v^*$) are considered applicable, with perhaps slight modification, to other gasoline powered vehicles similar in size and construction to the model M-34 vehicle.

Protective Passive Defense Features and Reduction of Target Vulnerability to Fragment Impact

The idea of employing protective passive defense measures to reduce the vulnerability of a prospective target to fragment impact is not new. Consideration of such devices for use on a target vehicle similar to the one described herein was urged in Reference 4, and data supporting the desirability of such consideration are presented there. The passive defense features considered in the present study are perhaps the ones most usually thought of in the case of unarmored vehicles – the thickening of the "skin" or outer surface of the target or the supplying of outer surface protection for areas containing vulnerable components (in the present case, radiator louvres and a metal top cab closure) where none presently exists. It is also possible to provide passive protection in other ways such as providing shielding for individual vulnerable components.

The amount of additional protection required to reduce the vulnerability of a given target from that associated with its usual configuration to some predetermined level will, of course, be dependent on the pertinent characteristics of the weapon (e.g., fragment impact weight and velocity) relative to which protection is desired. Complete protection of a given target with respect to every conceivable weapon which may be used against it is usually an unattainable goal. Penalties in dollar cost and labor cost of such protection could be prohibitive. Also, for mobile targets, the weight penalty of such total protection may severely curtail or eliminate a required capability of target movement. It is generally possible, however, to make a "trade off" so that a reasonable degree of protection against a limited number of weapons may be obtained without imposition of overly restrictive penalties.

It is pertinent to note that there may be advantages to be gained in installing the passive defense features considered in addition to the protection afforded to the vulnerable components listed in Section II. The radiator louvres which protect vulnerable components of the engine from fragment impact damage also provide thermal control which is very useful for cold weather operation. The metal top cab closure, in addition to the protection afforded to the vulnerable components mentioned above, affords some protection against fragment impact damage to operating personnel (who may not be immediately replaceable as assumed for the purposes of this study) and to cargo (which may, contrary to the assumptions made for this study, contribute to vehicle vulnerable area).

There has been no attempt made in the present study to estimate material or labor costs incidental to supplying or installing protective passive defense features on the basic version T_1 of the model M-34 vehicle. It is noted, however, that a metal top cab closure is available (Reference 3) for this model vehicle. The effect on vehicle performance capability and on repairability of installing certain passive defense features has been considered, and the following observations have been made. (A review of the characteristics, listed in Section I, of the four versions of the vehicle is suggested at this point.) The hood top of the basic version T_1 of the vehicle weighs approximately 54.3 pounds, and the two hood side panels have a combined weight of approximately 16.74 pounds. The total weight penalty involved in changing from vehicle version T_1 (with no passive defense features) to the best protected version T_4 (with double thickness hood top and side panels, radiator louvres, and a metal top cab closure) is estimated not to exceed 200 pounds. This is certainly not a sufficient penalty to noticeably

affect the carrying capacity, speed, or maneuverability of the 2.5-ton target vehicle. Furthermore, the increase (doubling) of hood top and side panel weight should not seriously affect the time or labor required in making repairs which require raising the hood top or removing the side panels.

The study upon which this report is based is concerned only with an attempt to evaluate and compare the degree of protection against fragment impact damage, relative to a selected range of fragment impact weights and velocities, afforded to the vulnerable components (See Section II.) of each of four versions of the target vehicle by the different passive defense features of the target versions. (It is noted that the four versions of the vehicle differ only in respect to passive defense features. Engines, power trains, and all other features are identical on all four versions.) Tables VI through IX in Section IV present values of averaged vulnerable area $\bar{A}_v$ and $\bar{A}_v^*$ for each of the four versions of the vehicle, T_1, T_2, T_3, and T_4 (described in Section I), relative to various fragment impact conditions and each of two mobility kill categories. For each version of the vehicle, the tabular data referred to are similar to fragment impact vulnerability data furnished for other vehicular targets in previous BAL vulnerability reports (See Bibliography.). It is asserted that the tabular values of averaged vehicle vulnerable area~~s $\bar{A}_v$ and~~ $\bar{A}_v^*$ which are associated with a given mobility kill category and a given fragment impact weight and velocity for each of four versions of the target vehicle are comparable. It is further asserted that differences in these values of averaged vehicle vulnerable areas (particularly of $\bar{A}_v^*$), over the four target versions, form a reasonable measure of the relative protective efficiency of the passive defense features of each of the target versions with respect to a given mobility kill

category and set of fragment impact conditions.

Figures 4 and 5 in Section IV present typical families of curves depicting the relationship between averaged vehicle vulnerable area $\bar{A}_v^*$ and fragment impact weight and velocity for a given mobility kill category and for the basic version T_1 of the target vehicle. The interesting feature of these families of curves is the clear indication of a relative maximum value of $\bar{A}_v^*$ in the impact velocity interval $4000 \leq v \leq 7000$ for each curve. No similar graphic representations of the relationship between averaged vehicle vulnerable area and fragment impact conditions have been provided for target versions T_2, T_3, or T_4. However, such representations would reveal the phenomenon of a relative maximum value of $\bar{A}_v^*$ occurring in the same velocity interval $4000 \leq v \leq 7000$ for these modified versions of the vehicle.

The mid-range, $4000 \leq v \leq 7000$, of the total range, $1000 \leq v \leq 10{,}000$, of fragment impact velocities considered in the present study is known to be of general interest to vehicle vulnerability analysts. Consequently, it is assumed that minimization of the relative maximum values of vehicle vulnerable area, which occur for fragment impact velocities in the mid-range interval, is also of general interest. Table II in the Summary (page 5) has been constructed to show the degradation of maximum values of $\bar{A}_v^*$ for the basic version T_1 of the target vehicle which results from the employment of protective passive defense measures on target versions T_2, T_3, and T_4.

The data in Table II are not intended to be and should not be construed to be anything more than a measure of the relative effectiveness of

several protective passive defense measures with respect to a range of fragment impact conditions. The user must decide what percent of degradation in vehicle vulnerable area is desirable, and then examine Table II to see whether it can be attained by employment of the passive defense measures considered and for what fragment impact conditions it can be accomplished. For example, assume that protective measures which produce a degradation of ten percent or more in values of vehicle vulnerable area are deemed worthy of consideration. Then the Table II data reveal that: 1) for mobility kill A Category, the desired reduction can be accomplished for fragment impact weights of 10 to 15 grains by increasing hood top and side panel thickness from 0.040 inches (version T_1) to 0.060 inches (version T_2), for fragment impact weights of 10 to about 30 grains by further increases of hood top and side panel thickness to 0.080 inches (version T_3), and for fragment weights of 10 to 120 grains by employing 0.080 inch hood top and side panel thickness and adding radiator louvres and a metal cab top as specified for version T_4; 2) for mobility kill B Category, the desired reduction can be accomplished for fragment weight of 10 grains by employment of protective passive defense features associated with version T_2, for fragment weights of 10 to 30 grains by employment of such features associated with version T_3, and for fragment weights of 5 to 30 grains by employment of such features associated with version T_4.

In general, the degradation effects of the protective passive defense measures noted in Table II are applicable to fragments with impact velocities in the upper and lower extremities of the velocity range $1000 \leq v \leq 10{,}000$. However, in both upper and lower extremities of the fragment impact velocity range, a ten percent or greater reduction in expected values of vehicle vulnerable area associated with the basic version T_1 of the target

vehicle can be accomplished for a greater range of fragment impact weights (up to impact weights of 120 to 240 grains, particularly for mobility kill, A Category) by employment of the same passive defense features. Of course, the expected values of $\bar{A}_v^*$ associated with extremes of impact velocity for all fragments are close to zero for mobility kill A Category as also are those associated with extreme low velocities for mobility kill B Category, and consequently, care must be taken in interpreting statements of relative protective effectiveness based on reduction percentages alone.

For all fragment impact conditions considered, i.e., all combinations of fragment impact weight and velocity for which target vulnerability data are furnished herein, the protective passive defense features associated with target version T_4 appear to be at least 1.5 to 3.0 times as effective as the protective passive defense features associated with target version T_2 and at least 1.2 to 2.0 times as effective as the protective passive defense features associated with target version T_3 in reducing target vulnerable area associated with basic target version T_1. The largest reductions in target vulnerable area attributable to the passive defense features are associated with target version T_4, with mobility kill B Category, and with the smaller, low-velocity fragments. These reductions are due largely to protection afforded to one of the larger and the most vulnerable of the components associated with B Category, the radiator, by the radiator louvres and by the metal cab top.

The following subsection contains a discussion of the vulnerability of the basic version T_1 of the target vehicle associated with two small shaped charges. It is felt that none of the protective passive defense features discussed in this subsection would significantly affect the target

vulnerability with respect to these shaped charges.

Vehicle Vulnerability Associated with Shaped Charges

The results of the investigation of the vulnerability of the basic version T_1 of the target vehicle to each of the two small shaped charges considered are presented in Figures 6, 7, 8, and 9 and in Table X in Section IV. The graphic description of the relationship between values of vehicle vulnerable area A_v and attack aspect (θ, ϕ), presented in Figures 6, 7, 8, and 9, has not been included in previous ground vehicle vulnerability reports published by BAL. It is included here in an attempt to provide a dramatic answer to questions regarding the degree of left-to-right symmetry of a vehicle with respect to vulnerable area data which are not averaged. The model M-34 vehicle exhibits a considerable degree of left-to-right symmetry, as do most automotive ground vehicles, with respect to presented area. However, and this is also true of most automotive ground vehicles, a remarkable lack of left-to-right symmetry exists for the model M-34 vehicle with respect to unaveraged vulnerable area data. The distribution of such vulnerable area data for a given weapon and target will vary, as indicated in the figures referred to above, from one attack elevation to another. The distribution will also vary from weapon to weapon for a given target, and it will usually vary considerably from target to target regardless of the weapons considered. It is this lack of symmetry in unaveraged vulnerability data and this tendency to vary considerably from target to target which makes it inadvisable to extrapolate such data from one target to another.

A comparison of the vehicle vulnerability data associated with the shaped charges, presented in Table X, and similar data associated with

fragment impact, presented in Tables VI through IX, for target version T_1 indicates that the model M-34 vehicle is considerably more vulnerable to either of the two shaped charges (the 1.0-inch diameter or the 1.8-inch diameter shaped charge) than it is to any fragment impact weight-velocity combination. This is true regardless of the mobility kill category considered. If differences between values of averaged vehicle vulnerable area $\bar{A}_v^*$ associated with a given fragment impact weight-velocity combination and with a given shaped charge are assumed to be a reasonable measure of relative effectiveness of the projectiles with respect to a given target version and mobility kill category, then the following conclusions can be drawn from a comparison of the maximum values of $\bar{A}_v^*$ associated with a fragment with impact weight $w = 1000$ and the values of $\bar{A}_v^*$ associated with a shaped charge. With respect to mobility kill A Category, the 1.0-inch diameter shaped charge is at least 4.7 times as effective and the 1.8-inch diameter shaped charge is at least 5.5 times as effective as the 1000 grain fragment. With respect to mobility kill B Category, the 1.0-inch diameter shaped charge is at least 1.2 times as effective and the 1.8-inch diameter shaped charge is at least 1.5 times as effective as the 1000 grain fragment. The greater relative effectiveness of the shaped charges over the 1000 grain fragment with respect to mobility kill A Category reflects, mainly, the fact that the fuel tank is considered vulnerable to the shaped charges but not to the fragment with respect to mobility kill A Category while it is vulnerable both to shaped charges and to the fragment, although not to the same extent, with respect to mobility kill B Category.

Differences between values of averaged vehicle vulnerable area associated with either mobility kill category and each of the shaped charges are not large. On the average, the vehicle vulnerable area associated with the

larger shaped charge is less than twenty percent greater than that associated with the smaller shaped charge. It is estimated that vehicle vulnerable area associated with any larger shaped charge up to one with, perhaps, a 4.0-inch diameter will be only slightly greater than that associated with the 1.8-inch diameter shaped charge considered in this report. For shaped charges with diameters in excess of 4.0 inches, it may be necessary to reevaluate target vulnerability by taking into consideration that components of the vehicle in addition to those listed in Section II may be vulnerable to such shaped charges.

The foregoing remarks in this subsection and the vehicle vulnerability estimates presented in Section IV for shaped charges apply specifically to bare shaped charges such as those employed in the experimental firing program, described in Section III. For encased shaped charges with characteristics (charge weight; liner design, weight, composition, and apex angle; and diameter) equivalent to those of the shaped charges considered here, the vehicle vulnerability estimates in Section IV are possibly quite conservative. It is expected that the encasement would enhance the blast effect on target components, which was negligible for the bare shaped charges considered, and that the target components could be damaged significantly by fragments from the shaped charge casing. In either case, the target vulnerable area associated with an encased shaped charge would be greater than that associated with a bare shaped charge with similar characteristics.

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13. ABSTRACT

The vulnerability of the U.S. Army, model M-34, 2.5-ton, 6 x 6, gasoline powered cargo truck to single-shot fragment impacts and to direct hits with single, small, shaped charges is discussed. The basic version of the vehicle is unarmored. The degradation of vulnerability resulting from protective passive defense measures is investigated by considering the basic version and three modified versions of the vehicle. The four versions ~~of the~~ vehicle differ only in hood top and hood side panel thickness or in other protection afforded to engine components. (U)

Nine fragment impact weights, ranging from 5 grains to 1000 grains, and sixteen fragment impact velocities, ranging from 125 fps to 10,000 fps are considered relative to each of two mobility kill categories, A (two-minute) and B (twenty-minute), and to each version of the vehicle. Two shaped charges are considered relative to each of the two mobility kill categories, A and B, and to the basic version of the vehicle. (U)

Estimates of vehicle vulnerable area, averaged over azimuth for selected elevation angles and averaged over both elevation and azimuth, are presented for each of the four versions of the vehicle relative to various combinations of fragment impact weight, fragment impact velocity, and kill category. Similar averaged vulnerable area estimates are presented for the basic vehicle only relative to each of the two shaped charges. (U)

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Protective Passive Defense Measures						
Weapon Effectiveness: single fragment						
shaped charge						
Engines (automotive)						
Penetration						
Contract DA-18-001-AMC-753(X)						

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